THE ENGINEER

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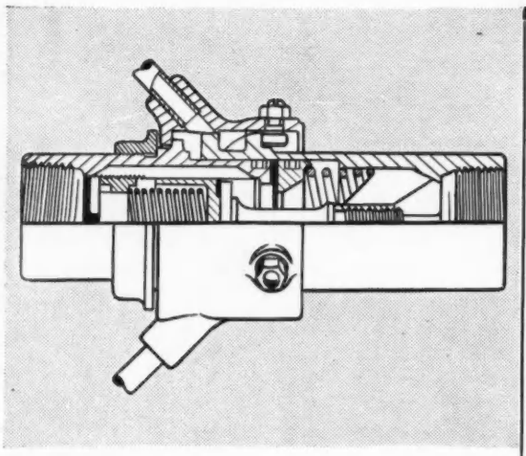

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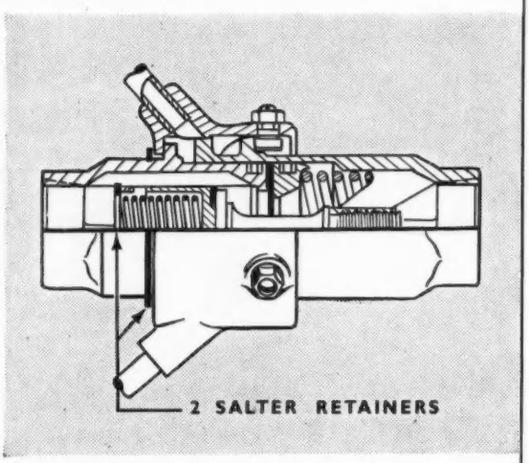

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No. 5483 **FEBRUARY 24, 1961** VOL. 211

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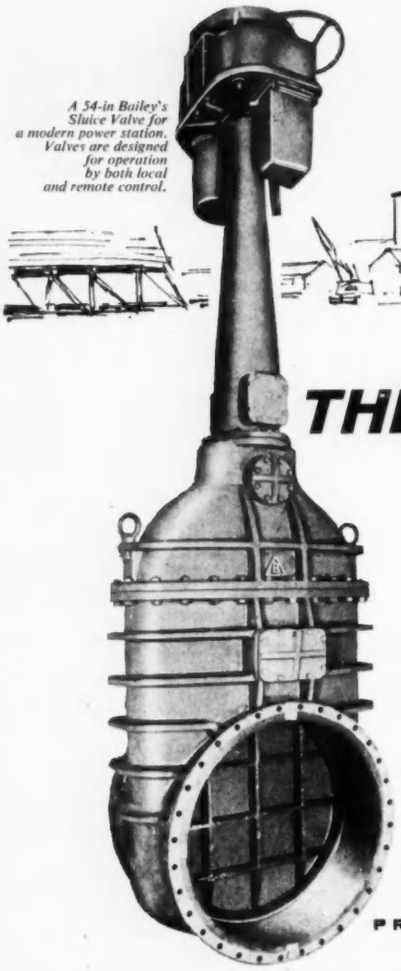

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THE ENGINEER

No. 5483 FEBRUARY 24, 1961 Vol. 211

NO CHANGE IN PRINCIPLE

Contrary to previous Defence White Papers, the Government's Report on Defence presented last week dealt almost entirely with policy. It was left to the Service Ministers to report in the Estimates on progress and developments in the armed forces. The Report forecasts no change in the defence policy approved in 1957. Britain is to continue to contribute to the Allied nuclear deterrent while maintaining her Fighting Services on a voluntary basis. The total cost of defence during the coming year is estimated at £1655½ million. The taxpayer has thus to provide £51,000,000 more than last year when he was helped by a contribution of £13,000,000 from Germany towards the cost of the British forces in Europe. But there is a marked change of emphasis on priorities. The position of nuclear stalemate that has now been reached is recognised and emphasis is laid on the need to attach greater importance to the conventional forces. It is indeed refreshing in this connection to read that " . . . many of our most important responsibilities are not concerned with the direct deterrence of all out war." For the first time mention is made in a Defence White Paper of the very large armed forces maintained by China, though it is clear from the disposition of the small Fleet that the defence chiefs are well aware of the possibility of Chinese military intervention in inflammable areas in the Far East. Already one of the three operational carriers, a "Commando" carrier, a cruiser and the existing amphibious warfare vessels, are stationed or have been allocated for duty east of Suez and another ship is under conversion as a second "Commando" carrier.

Although the White Paper does not discuss the question, it seems that the Government has decided against building — at any rate for some years — "Polaris" submarines. V-bombers provide the most economical delivery system for the strategic nuclear deterrent and their retaliatory capacity and efficiency are being constantly increased by wider dispersal and shorter reaction time. The "Blue Steel" stand-off power bomb, with its range of 200 to 300 miles — to be replaced later by the ballastic rocket "Skybolt" — is expected to counter probable improvements in fighter and missile defence over the next ten years. The Mark I V-bombers will require to be replaced by the improved Mark II version to take the new deterrent missiles. But this will be a gradual process and in view of their relatively low cost as a delivery vehicle, there seems no reason why Britain should not continue until 1970 to provide an effective and adequate share of the Allied strategic deterrent. After that date, however, some form of seaborne deterrent seems likely to be needed to supplement if not replace the V-bomber. An effective seaborne missile is available in the "Polaris." But "Polaris" submarines or other large vessels are very expensive and take a long time to build. It would thus be profitable for Parliament to consider now how Britain is to remain a welfare state and build submarines costing over £40,000,000 for the sole purpose of providing a nuclear deterrent. Though the Minister of Defence was not in a position to discuss in the White Paper the American offer of five "Polaris" submarines to N.A.T.O., it was suggested in these columns a week ago that both Britain and N.A.T.O. would benefit most from the offer if the Royal Navy manned and operated these vessels on behalf of N.A.T.O. With the existing force of V-bombers — whose construction was started by the Opposition when in power in 1948 — with the deterrent base now made available for the Americans in the Holy Loch; and with the manning and operating of these five vessels on behalf of N.A.T.O. Britain would be providing a deterrent presenting great diversity of attack, adequate for a great power and at minimum cost, while giving no encouragement to other European nations to build their own nuclear missiles.

The Minister seems confident that he will obtain the number of voluntary recruits required. But his White Paper leaves two questions unanswered which it is to be hoped will be discussed in Parliament. Now that the early warning arrangements give ample time for V-bombers to become airborne as a "second strike" weapon, what is the purpose of the "Bloodhound" and other shore based anti-aircraft missiles? Little can or should be saved on Fighter Command which, now under the control of SACEUR, will in future increase the strength of the "Shield" in Europe. But the protection of the deterrent bases has hitherto been costing from 5 to 10 per cent of the defence budget and with the cancellation of the "Blue Streak" substantial savings on this item would seem to be possible. Nor does the Minister explain why the Royal Navy's tactical aircraft require to be equipped with nuclear weapons (Par. 18). Are these missiles to be used against warships? A legitimate use, certainly, though present naval defence policy does not suggest that surface ship attack is a serious menace. Or are they merely to supplement the attacks of medium range bombers from the United States super-carriers by bombarding enemy installations on or near the coast in an all out mass destruction war? If so it must be visualised that the Royal Navy will continue to fight even though the British nation takes no other effective part in the war.

ENGINEERS AND THE DEVELOPING COUNTRIES

In delivering the Tenth Hinchley Memorial Lecture, entitled "Science and Technology and the Developing Countries," to the Institution of Chemical Engineers on February 15, Professor P. M. S. Blackett, M.A., F.R.S., noted a change in the attitude of the West to those countries which had not benefited from the developments which had raised the standard of life in Europe and certain associated countries overseas. The reasons for the changes during the last 200 years appeared to him a complex of many causes unrelated to any differences of innate ability. During this period, he said, the West had moved from equality to being ten times as rich in terms

of wealth per head as the poorer countries. Now those latter countries are endeavouring to expedite their economic growth and not just wait upon events. But owing to the heavy investment required (approximately 12 per cent of the national income) to bring about a rise of incomes of 2 per cent per head, a mixed economy is necessary and the Professor emphasised the need for assigning the right priorities for investments. He pointed out that the buying of consumer goods only raised the standard of life for a short term, while capital goods were essential to the promotion of growth. Therefore emerging countries, although impatient for progress, must actually cut down on consumer goods at first and concentrate on acquiring capital goods. They needed to sacrifice an immediate rise in standards in order to ensure the promotion of economic growth and a higher standard of life in the longer term. In discussing capital goods the Professor called attention to the fact that in the West capital is cheap and labour is dear whereas the opposite rules in the underdeveloped countries. Thus a different development philosophy is required. Instead of replacing labour by capital expenditure on machines, what is necessary is the adoption of technologies which will increase man's capacity at small capital cost. In terms of food production this means that an increased yield per acre is more important than a larger output per man.

In the years immediately after the war the fear was expressed that it would prove impossible to feed the rapidly expanding world population. But such fears have since evaporated. Professor Blackett said that the application of known technology would suffice to produce enough food to feed a population expected to reach 6000 million by AD 2000. The significant part to be played by nitrogen fertilisers in expanding food supplies was underlined by figures quoted for Japan and India. The former uses 100 lb. per acre, compared with India's 1 lb., and achieves four times the yield of rice. Thus extra supplies of fertiliser are essential to improve social conditions and an increase from the current world production of 10,000,000 tons per annum to 50,000,000 tons is thought to be the measure of expansion necessary by the end of the century. Professor Blackett recalled the construction of the Sindhri plant in India, at a cost of £25,000,000, to produce 350,000 tons of sulphate of ammonia a year and said that two such plants would be required every year to raise the nutritional level and provide for the increasing population. But the capital outlay involved was great and he advised the technological-economic study of the optimum size of chemical plant, taking into account the shortage of capital and the abundance of labour. Reduction in cost might bring such plants within the financial scope of local government or even the private investor.

From the professor's address it is clear that most emergent nations are unable, under modern conditions, to achieve what has been termed the "take off into sustained growth" without financial and technical help from outside. But the nations concerned need to be persuaded that, however great their degree of impatience for progress, the aid received must be spent on capital goods designed to effect improvement in the long run rather than on consumption goods which can bring about only an ephemeral rise in the standard of living. Furthermore, whatever is done should be designed to raise the efficiency of labour rather than to displace it by machines. For, at present, any displacement of labour creates rather than solves problems. The situation is that so long as labour remains cheap it is uneconomic to expend much capital on labour-saving equipment. Engineers who design plants for installation in undeveloped countries need to bear the point in mind.

GRANTS TO STUDENTS

Recently Sir David Eccles in a written reply to a question in the House gave information about the decisions reached by the Government on "the details of the scale of parental contributions in respect to grants to students" which will come into force on October 1 this year. The idea that any kind of means test on the parents should be abolished has been rejected. Instead substantial reductions are to be made. On the present scale parental contributions are calculated at 14 per cent of the balance of income in excess of £450 (the figures are slightly different for Scotland). The revised scale will require a contribution at the rate of 8 per cent of the balance of income in excess of £600, no contribution being required from parents whose balance of income is less than £700. Balance of income refers to gross income less certain allowances for superannuation, insurance, &c. In calculating it certain changes are to be made which will be favourable to parents. As examples of the effect of the various changes the following are worth quoting. If there is an only child at a university parental contribution will begin as the gross income approaches £750 instead of £500. Towards the top end of the scale the revised contribution of £256 will be payable on a gross income of £3,500 as compared with £403 at present.

Any reduction in the parental contributions is, of course, welcome. But we have been far from alone in urging upon the Government that the whole principle of the means test is wrong and inequitable. The idea behind it appears to be that people who are "rich" should be capable of paying for the education of their children — though how, nowadays, anyone earning less than £2,000 a year and with a child or children can be regarded as "rich" it takes a socialist to explain. A large number of engineers at an age to have children at a university have salaries in this region. It is to be feared that even under the new proposals many will find it impossible to allow their children to benefit from university education. But surely the government has far too narrow a way of looking at the situation. The really important thing is to ensure that every youngster with brains enough to qualify for a grant should go to a university. It should surely be noted, too, that it is the youngster himself and not his parents who qualifies for the grant. In the national interest there should be no possibility that a youngster capable of benefiting from university education should be unable to attend the university simply because his supposedly "rich" parents are so supposedly (or even really) "spendthrift" that they cannot afford to contribute towards the cost. We have consistently maintained that since a grant is in effect earned by a youngster it should be regarded as his income and be his independently of the earnings of his parents — provided of course that he attends the university and continues to benefit from his studies there. In short, if there is to be a means test at all it should apply to the youngster's means; not to those of his parents.

Some of those who disagree with us will no doubt point out that parents with smaller incomes actually benefit more under the new Governmental proposals than they would were a grant taken to be part of the youngster's income. For under the latter idea, supposing the grant to exceed £100 the parents would lose the children's allowance for income tax purposes; whereas under the Government's proposals the allowance is not

lost and the revised contribution, for example for a parent with an only child at a university, only rises to equality with the value of the tax allowance at a gross income of around £1,400 a year. The answer to the criticism, of course, is to criticise in return the rather absurd rigidity, not to speak of the inadequacy, of the figure of £100 per year for a child's income which if exceeded leads to the cancellation of the child's allowance for income tax purposes. That allowance should surely be graded so as to disappear gradually as the income of the child gets larger, ceasing altogether at some substantially higher figure than a mere £100.

COMMONWEALTH TRAINING WEEK

The week ending June 24 this year is to be a very special week for young people. When the Duke of Edinburgh was in Australia he took notice of what is termed there a State Apprenticeship Week. From that experience he conceived the idea of similar "weeks" to be held throughout the Commonwealth. The first such "Commonwealth Technical Training Week" opens in this country on May 29. It has as its aim and object, to quote from a document issued by its Central Advisory Committee, "to stimulate awareness of the responsibility of the community towards young people entering employment; to stress the importance of schemes of induction and training both for the benefit of individual firms and in the interests of young people themselves; to give increased opportunity to young people to learn of the opportunities available for training and education; and generally to emphasise the significant place of the young worker in society."

The City and Guilds of London Institute has undertaken responsibility for the central organisation. But the detailed organisation of the Week will lie in the hands of local authorities. Though such authorities will be able to do much in the way of organising civic functions, local careers' exhibitions and exhibitions of craftsmanship, competitions for young people connected with crafts, and so on, the co-operation of local firms and industrial organisations and societies and institutions will be essential if the Week is to prove a success. Many ways in which a contribution can be made will suggest themselves to members of firms and other organisations. Many works, for example, hold annual prize-givings of one kind or another for apprentices and students. It would be particularly appropriate to hold such events during the Week. The date is not very appropriate for colleges to do the same thing. But both colleges and firms could, and no doubt will, organise "Open Days" during the Week at which especially the work of students and apprentices will be displayed. For institutions and societies, no doubt, the main contribution to the Week will lie in taking part in Careers Exhibitions by making available diagrams and literature. Very appropriately and just at the right moment the Institution of Mechanical Engineers has brought out a pamphlet entitled "The Education and Training of Mechanical Engineers." Other institutions and firms have similar documents available. The various exhibitions and conventions to be held will bring such documents to the notice of young people up and down the country. The Week is intended to cover all forms of training for employment. But it will obviously be of special interest to engineers and we commend it to the notice of engineering firms and organisations.

VOTING FOR AN INSTITUTION MERGER

The results of the postal referendum held both by the Institution of Civil Engineers and the Institution of Municipal Engineers on the proposed amalgamation of the two Institutions were announced last week. The voting was as follows:

	Corporate members entitled to vote	Votes received	For amalgamation	Against amalgamation
I.C.E.	16,544	7,690	5,757	1,955
I.Mun.E.	5,765	5,015	3,108	1,905

The results show a majority in favour of amalgamation of approximately 75 and 62 per cent respectively. An astonishingly high proportion—about 85 per cent—of the I.Mun.E. voting papers were returned, and the return approaching 50 per cent registered by the I.C.E. is very good, measured by the responses which major institutions seem to receive generally. It is perhaps of interest that the voting against amalgamation was almost the same in both ballots; possibly coincidentally, the number of people entitled to vote in both ballots (i.e. corporate members of both institutions) is 2270.

As far as the I.C.E. is concerned, the policy of amalgamation is now settled, but the I.Mun.E. has no provision in its constitution for a postal vote. The I.Mun.E. vote is therefore only an expression of the opinion of its members, and a decisive vote, which entitles the I.Mun.E. to act, is to be taken at the special general meeting to be held at Brighton in June. It would appear that, unless a "pressure group" dominates the meeting, the majority required is likely to be obtained. If so, then application for the amalgamation will be made to the Privy Council. The issues involved in amalgamation were discussed in a "leader" in our issue of October 21 last.

The Engineer—100 Years Ago (FEBRUARY 22, 1861)

"A New Suggestion for Preserving the Stone of Westminster Palace"

"At the discussion on this subject in the Institute of Architects, on 11th inst., Professor Hoffman, as reported in the *Builder*, said he wished to throw out a single suggestion. The resources of chemistry were not exhausted in the various processes which had been submitted to the public. There was, for instance, a substance which, in his opinion, promised much good. Silica quartz, combined with spirit of wine, formed silicic ether, which possessed such remarkable properties that he was surprised it had not been tried as a stone preservative. Silicic ether was a liquor which boiled at 400 deg. Fah., and contained 70 per cent. of pure quartz, and the remainder spirit of wine. It had the remarkable property of undergoing decomposition when left to the action of moist air. When left in an open vessel it gradually formed into a solid mass, which was as hard and imperishable as agate. The spirit of wine became separated when exposed to the atmosphere, and the hydrated quartz alone remained. This being the case, the question presented itself whether it would not be worth while to saturate a stone with the material, and ascertain whether the same result would not follow as in the open vessel when the ether was exposed to the air. He knew it might be said that the cost of the silicic ether would be too great to admit of its use on a large scale, but this difficulty might in course of time be got rid of."

Canadian Pacific Transcontinental Trains

THEIR MOTIVE POWER AND EQUIPMENT

By EDWARD H. LIVESAY

No. II—(*Continued from page* 239, *February* 17, 1961)

SO much for the rolling-stock; coming to the motive-power, the locomotives—one to four units are used, the latter in freight service—handling the transcontinental trains have been built by the General Electric Company at London, Ontario (Fig. 9). They are of the B_0-B_0 type, fitted with sixteen-cylinder, 1750 h.p. two-cycle motors, the two banks of cylinders, 8½in diameter by 10in stroke, set at 45 deg., are scavenged by a Roots blower, air being supplied by a three-cylinder stage compressor. The air-intake ports are in the cylinder walls, the exhaust valves, four per cylinder, in the heads. The oil-cooled pistons are aluminium, two connecting-rods driving on one crank, with a bearing between each. Engine revolutions vary from 275 r.p.m. idling to 835 r.p.m. at full throttle, controlled by an isochronous hydraulic governor.

The engine is direct coupled to a 600V generator, an 80kW alternator on the same shaft supplying current for the water-cooling fans and motor-blowers; the engine is generator-started. The B_0-B_0 trucks have nose-suspended motors, one to each axle; various gear ratios can be used, according to the service in which the locomotives are to be employed; for the transcontinental service the ratio is 58 : 19, giving a maximum speed of 89 m.p.h. Each traction motor is cooled by a 5 h.p. motor blower, and 9 h.p. motors drive the four roof-mounted radiator fans, which are thermostatically controlled.

During acceleration the motors are connected in (1) series-parallel; (2) series-parallel-shunt; (3) parallel; and (4) parallel-shunt. The handling of the locomotive is done in chief by five levers, three being on the controller-throttle, reverse and transition, the latter concerned with the four motor connections given above—and the other two the usual Westinghouse brake handles. The throttle lever regulates engine revolutions and the speed of the train; it has ten positions shown on an illuminated indicator above it, i.e., stop, idling, and one to eight running notches. To stop the engine—or engines if more than one unit is in use—a button on the end of the throttle lever is depressed, and the lever moved one step beyond the idling position; it cannot be moved beyond the idling position unless the button is pressed. Each notch on the throttle indicator raises the engine revolutions by seventy-five, from the 275 idling rate to 835 revolutions at full throttle. Mechanical interlocks prevent the throttle being opened more than one notch at a time, to obviate rough train handling; it can be closed in one sweep, though this should only be done in emergency. The reverse lever can only be moved when the engine is stationary; when in neutral, the power-circuits will not close if the throttle is opened. It can be removed from the controller when in neutral position, provided the throttle is at "Idle," and the transition lever is at "Off"; this locks the operating controls.

Though transition is now always automatic in both directions, forward or reverse, some of the older units required manual operation, so "A" units—those fitted with cabs—have the transition lever for use when coupled to "B" units not fitted with control apparatus, or automatic transition. An interlock in the controller prevents throttle opening unless the transition lever is in one of the four positions. When all the units of a locomotive have automatic transition, the lever is placed in No. 1, the series-parallel position, and the driver has no further control over transition. If any unit of a multiple locomotive has manual control, the latter must be started with the transition lever in No. 1 position, and then advanced to the other three positions consecutively, as set out in the following table, where the gear ratio is 58 : 19, for a maximum speed of 89 m.p.h.

From position	To position	At m.p.h.
1	2	26
2	3	34
3	4	71
4	3	71
3	2	34
2	1	26

In the same way, when decreasing speed, the lever must be returned from position to position. Manual transition cannot be made from 2 to 3 or vice versa unless the throttle lever is in No. 6 notch or lower.

Manual operation of the transition lever is also necessary where the locomotive is arranged for dynamic braking; when moved to the "Off" position the braking circuit is partially closed, and to the "B" position the circuit is complete; moving it still further to the right of "B" increases the braking effect. The dynamic brake is most effective at speeds from 15 to 25 m.p.h., and least so at 10 m.p.h. or less.

The ammeter, with its dial graduated from 0 to 1500, indicates closely the load and pull of the engine; there is a table below the dial showing the time overload permissible, and the maximum amperage, 600, allowed when dynamic braking is in operation. At continuous rating the figure is 825A; two hours 865; one hour 900; half an hour 925, and quarter of an hour 950.

The instrument panel has a wheel slip indicator showing when one or more pairs of wheels are slipping. If the light flashes repeatedly the throttle should be reduced, and sand used if necessary. In the same way if the dynamic brake is overloaded, the warning light calls for easing.

Two safety controls are fitted, according to the type of engine—either a dead-man's pedal or a hinged brake valve handle, which operates when the handle is depressed far enough to make contact with the sanding bail. One or other of these devices must be kept depressed while the locomotive is running. Should both be released at the same time automatic application of the brake results.* Other devices are windshield wipers, horns—air-operated by pull-cords—cab heaters, using hot water from the engine; motor-driven fans for air circulation; window defrosters taking the shape of a motor-driven fan which blows heated air on to the inside of the front windows.

The speed recorder, driven from the first axle of an "A" unit, includes a recording tape and a device that applies the brakes when the maximum speed allowed is exceeded and simultaneously shuts off engine power, slowing it down to idling revolutions.

The trucks (Fig. 8) have outside swing hanger suspension, which gives increased stability on curves, better riding and reduced body roll; all the axles on General Motors locomotives have Hyatt roller bearings, with a stench bomb fitted to each journal box releasing a pungent odour if the temperature exceeds 220 deg. Fah.†

Fig. 9 shows the arrangement of the engine-room, and is largely self-explanatory. Engine revolutions are controlled by the throttle through an electro-hydraulic governor which stops the engine in the event of low oil-pressure or high vacuum on the suction side of the lubricating-oil pump; when this occurs, if the engine is restarted, and run at idling speed, the governor will again stop the engine after forty seconds if the condition that caused the original shut-down has not been corrected. It is bad practice to attempt repeated restarting of the engine in the face of persistent governor shut-downs; further, if it is attempted to run the engine at above idling speed during

* Only the pedal is used on C.P.R. locomotives.—E.H.L.

† This reminds one of the "stink bomb" fitted to the big-ends of inside connecting-rods on the Eastern Region "A" class "Pacifics," a warning device developed and applied to these engines, unless I am mistaken, during or after the war, and of considerable merit; the inside big-end was rather the Achilles heel of the class. It would be interesting to know whether the idea was first associated with steam or diesel power, or if both devices had a common earlier ancestor.—E. H. L.

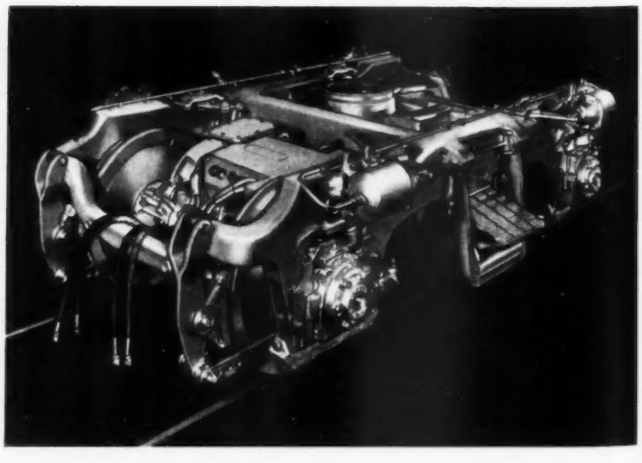


Fig. 8—Diesel-electric motor truck

the forty-second delay period, the governor will stop the engine at once if oil pressure is low, or oil pump suction high. If engine revolutions exceed approximately 910 r.p.m. a trip device—apart from the governor—stops the engine. A load regulator controlled by the lubricating oil pressure automatically varies the field strength in the generator, thus maintaining a power output corresponding to definite fuel consumption determined by the throttle position. A hand brake is fitted to all units, both "A" and "B" type; instructions are that it should always be applied when anyone is working around the trucks.‡ Engine cooling is thermostatically controlled, the water temperature being normally 120 deg. to 190 deg. The lubricating-oil pressure should be about 35 lb to 45 lb at 800 revolutions; when idling, at least 6 lb, the engine stopping automatically if the pressure should fall dangerously low. The fuel injectors are supplied by an electrically driven pump and are controlled by the governor; the power output corresponds to the fuel consumption. This latter naturally is dependent chiefly on load and gradient factors; by example, a unit would consume about 150 gallons during the 136 miles, mostly climbing, between Calgary and Field, with an 800-ton train; presumably three units would be used.

Train heating is provided by a Vapor-Clarkson type generator, with which full pressure is reached in a few minutes after lighting up, the feedwater passing first through a heat exchanger, then an economiser, and thence to the three coils, in series. The fuel oil is sprayed through an atomiser in the firepot placed above the coils, the combustion gases passing first down through the coils and then up and out of the chimney. Maximum evaporation with the smaller

‡ In North America it was not customary to fit steam locomotives with hand brakes; when steam was up, in shed or yard, and work was being done round or under the engine, a large-link chain would be laid across the rail in front of and behind the point of contact between wheel-tread and rail, to act as a lock.—E. H. L.

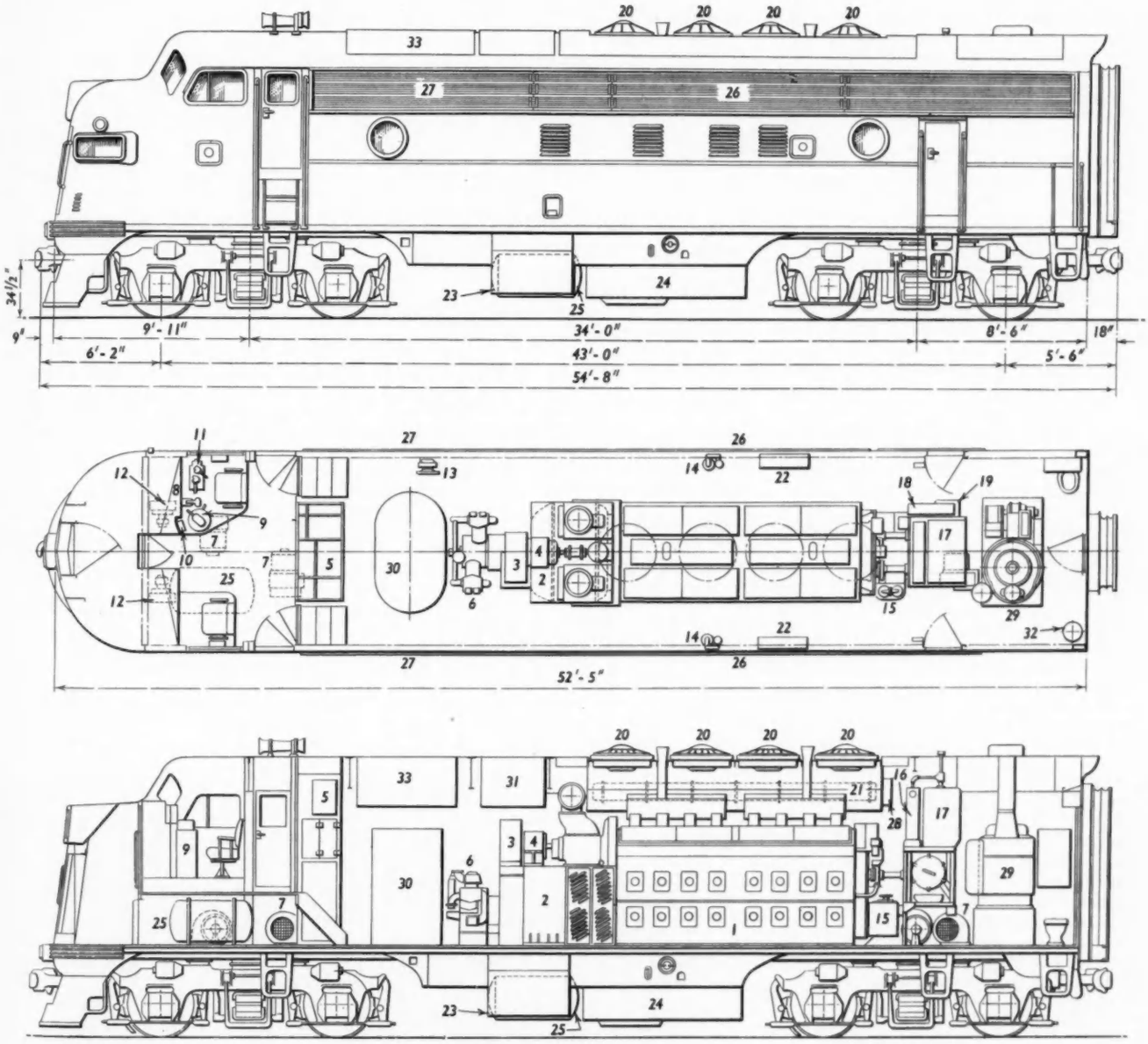
General dimensions and details; "F7" and "FP7" units

Weight, fully loaded, "F7A," approx.	102·6 tons
Weight, fully loaded, "FP7A," approx.	115 tons (with extra watertank for steam generator)
Weight fully loaded, "F7B," approx.	102·6 tons
Fuel capacity (per unit)	1000 gallons
Lubricating oil (per engine)	167 gallons
Cooling water, "A" unit	192 gallons
Cooling water, "B" unit	179 gallons
Steam generator water capacity "FP7A"	683 gallons vertical tank
Steam generator water capacity, "F7B"	1000 gallons vertical tank.

Gear ratios and maximum speeds:

65 : 12	55 m.p.h.	59 : 18	83 m.p.h.
62 : 15	65 m.p.h.	58 : 19	89 m.p.h.
61 : 16	71 m.p.h.	57 : 20	95 m.p.h.
60 : 17	77 m.p.h.	56 : 21	102 m.p.h.

Sand capacity	16 cubic feet
Wheel diameter	40in
Weight on drivers	100 per cent
Truck centres ("F7")	30ft
Truck centres ("FP7")	34ft
Truck wheel base	9ft
Minimum curve radius	250ft
Centre of gravity above rail	63ft
Length over couplers ("F7A")	50ft 8in
Length over couplers ("FP7A")	54ft 8in
Length over couplers ("F7B")	50ft
Maximum height above rail	15ft
Maximum width over handholds	10ft 8in



1—Engine.
2—Main generator and alternator.
3—Generator blower.
4—Auxiliary generator.
5—Control cabinet.
6—Air compressor.
7—Traction motor blower.
8—Instrument stand.
9—Control stand.
10—Speedometer recorder.
11—Air brake valve.
12—Cab heater.
13—Hand brake.
14—Fuel tank vent with flame arrestor.
15—Lubricant oil filler.
16—Lubricant oil cooler.
17—Engine water tank.
18—Engine control and instrument panel.
19—Load regulator.
20—34in fan and motor.
21—Radiator.
22—Sandbox.
23—Batteries.
24—Fuel tanks—1000 gallons.
25—Main air reservoir.
26—Air intake and shutters.
27—Air intake for grids and engine-room.
28—A.C. contactor cabinet.
29—Boiler.
30—Boiler water tank—720 gallons.
31—Boiler water tank—280 gallons.
32—Boiler water softener.
33—Dynamic brake grids and blowers.

Fig. 9—1750 h.p. diesel-electric locomotive

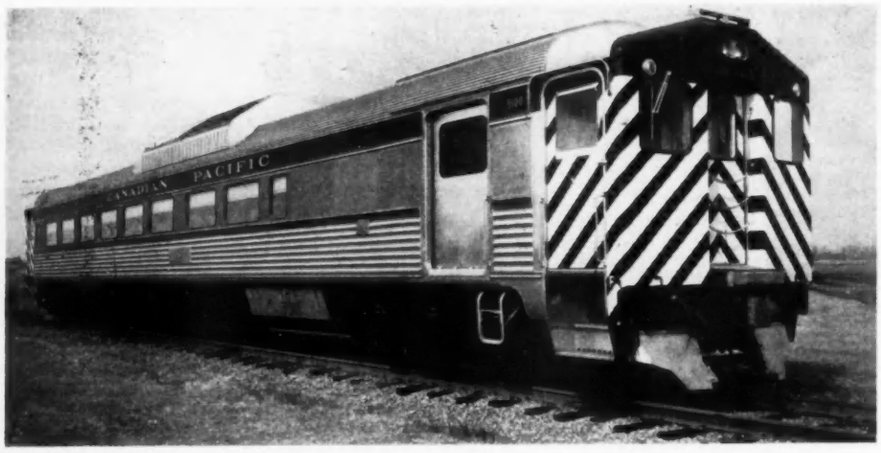


Fig. 10—Canadian Pacific R.D.C. 2 " Dayliner "

models is at the rate of about 300 gallons per hour, with normal pressure 150 lb but this might have to be raised to 250 lb in very cold weather, to get through to the rear of a long train, which—say, of fifteen vehicles—could extend to 1250ft, and be combating 90 deg. of frost.

Flange wear with the B_0-B_0 units is somewhat heavy, but is considerably reduced by the use of rail-lubricators where curvature is severe ; a possible reason suggests itself—heavily loaded four-wheeled trucks plus a low centre of gravity.

The equipment thus far dealt with is used to make up multi-vehicle trains, such as the transcontinental expresses, in which one or more diesel-electric units handle a number of coaches. Where subsidiary services do not call for this, rail-cars are employed, run either solo or coupled in pairs, just as is the case in Britain, and as I began a recent cross-Canada trip in one of them, and on my return broke the journey *en route* in another, it will be legitimate to describe them, all the more so as they are an important factor in the " dieselisation " of the C.P.R. I have no doubt that the number in operation in Canada and the States runs well into four figures. These R.D.C. (Fig. 10)—Anglicé, rail diesel cars—are the product of the Budd Company, Philadelphia, the same firm responsible for the coaches making up the " Canadian " trains, and the result of upwards of twenty years' experience and experimentation in the construction of lightweight stainless steel motor trains and self-powered cars. The design was based on various practical desiderata ; two engines were provided for greater reliability, with under-the-floor location for ease of handling and accessibility ; an engine can be taken out and another substituted in under two hours, without shop or pit being necessary. In addition, the failure of one engine does not immobilise the car, as the run can be completed at a reasonable speed on the other.

The cars run on two four-wheel bogies, the inner axle of each being driven by a six-cylinder, 275 h.p. horizontal diesel motor transmitting its power through a torque converter and reverse gear built integral with the engine. The trucks are fitted with disc brakes and the " Rolokron " anti-sliding device ; the interior of the car is air-conditioned and heated by radiators forming part of the engine-cooling system. The power/weight ratio, 8·68 h.p. per ton, is high, and gives rapid acceleration, the torque converter working with great smoothness, and preventing engine abuse by careless throttle operation ; it automatically locks into direct drive when a speed of 55 m.p.h. is reached. A cruising speed of about 70 m.p.h. is recommended, as this only calls for 55 per cent of the available power ; the maximum speed on the level with full load is 85 m.p.h. On 1 in 100 it is 62 ; on 1 in 50, 42; on 1 in 33, 28. Fifty-seven miles per hour is reached in 1 mile from a standing start, and 5 miles are covered in five minutes also from a standstill ; 44 m.p.h. is attained in sixty seconds.

The Budd concern draws attention to the possibility of making repairs to the engines in two ways : (1) by taking the car out of service while the repairs are being made, and (2) by taking the defective engine out of the car, replacing it by another, and returning the car to service in a couple of hours—the defective engine can be put to rights at leisure, and becomes a spare. The manufacturers favour the second plan, made practicable by the design ; the absence of spare engines is false economy, greatly reducing availability.

The cars are 85ft in length, the top of the dome 14ft 7in above rail-level, and the rest of the roof 13ft 1in. The truck wheel base is 8ft 6in, and wheel diameter 33in, with rims and hubs machined to give balance. The loaded weight of 55·5 tons includes 225 gallons water, 250 gallons fuel oil, 60 gallons engine and transmission lubricating oil, and 600 lb of sand. The body takes the form of a stainless steel box beam with a longitudinally corrugated roof welded to the ribs, a raised dome near the centre housing radiator, fans, inlet and exhaust pipes. The bogies are of the single equaliser, single bolster, swing hanger type with coil springs ; weight is saved by the abolition of end transoms, the absence of clasp brakes and gear making them unnecessary ; shock absorbers check vertical bolster motion. The axle drive comprises a twenty-six tooth spiral bevel gearing with a fifty-four-tooth ring-wheel bolted to a splined quill.

The engines are enclosed in sound-deadening boxes with drop doors, protecting them from damage due to flying ballast, &c., and keeping out dirt, snow, and ice ; temperature in them remains normal, and no induced ventilation is needed. The motorman's cab has an electric heater and circulating blower, and thermostatically controlled, electrically heated windows to prevent fogging and icing.

The motive-power and rolling stock of the new trains having been dealt with, it is now proposed to bring the passenger into association with both on a transcontinental journey, which will begin at Victoria, situated on the southern tip of Vancouver Island, the city originally intended to be the Western terminus of the railway. At that time, in the seventies, the plan was logical and attractive, as not only was Victoria, the capital of the province, already in being, but it was practically on the open waters of the Pacific, whereas Vancouver on the mainland did not even exist, and when ultimately it did, to reach it shipping would have to navigate the somewhat intricate island-studded, fog-infested Straits of Georgia. With Victoria as the terminus this would be avoided, and on paper, and in the mouths of politicians and promoters, the scheme was quite feasible. It was only necessary to throw a bridge across Seymour Narrows, where Vancouver Island appeared to come almost within a stone's throw of the mainland, run the rails across and connect them with the existing line extending from near Nanaimo to Esquimalt, built by Dunsmuir, the coal baron, in the sixties, and *voilà* ! the thing would be done. An Order in Council to this effect was actually passed in 1873 ordaining that Esquimalt, now a suburb of Victoria, and the Pacific Naval Base, should be the terminus of the C.P.R. The railway on Vancouver Island would become an integral part of the great transcontinental line that British Columbia had insisted should be built as the price of the province remaining in Confederation ; failing which, secession was threatened, with adherence to the United States. But—" the best laid schemes of

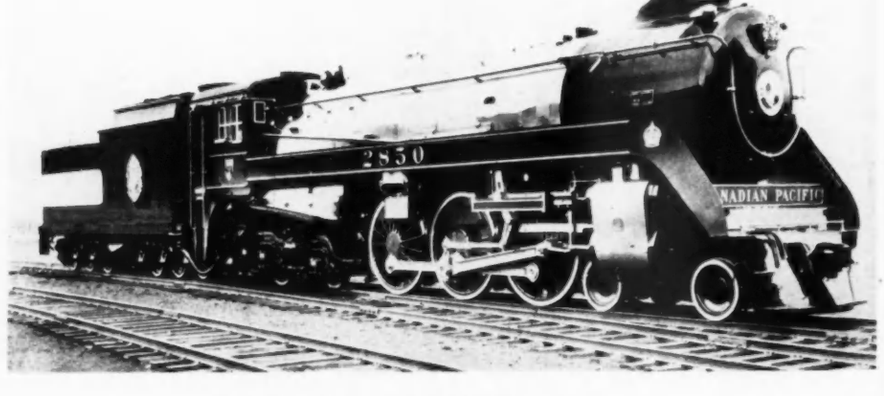


Fig. 11—4-6-4 " Hudson " express locomotive

mice and men "—on investigation and more mature consideration, that part of the plan visualising Victoria as the terminal point proved impracticable. It was found that Seymour Narrows did not actually separate Vancouver Island from the mainland at all, but only from another island, and that in turn from yet others, threaded by fjord-like channels ; the islands would be mere stepping-stones to more promising terrain inland. Moreover, the cost of building a railway through this rugged, rocky wilderness would have been astronomical. Probably 150 miles of line would have been necessary to connect with the proposed route through the Thompson Canyon at, say, Lytton or Ashcroft ; let the reader look at a map of British Columbia for confirmation ; the difficulty of the route will be evident. Finally, neither Victoria nor Esquimalt had an adequate harbour—the latter's anyway was claimed by the Navy—whereas Vancouver, sited on the shores of Burrard Inlet, had a superb harbour, this no doubt being the deciding factor in the final choice. Thus Vancouver came into existence, and has grown and flourished ever since like a green bay tree, nourished by land roots extending across the continent to the east, and marine tentacles spanning the Pacific to the south and west. Victoria, on the other hand, has remained unconnected by rail with the mainland, a governmental and residential city, dependent for its attractions chiefly on being such, and " a little bit of Old England "—which in the writer's opinion it emphatically is not in these days, however true it may have been in the past. The only real similarity lies in the climate, which is very like that of the south-east of England—but I digress.

Though the Seymour Narrows were never bridged, ultimately the C.P.R. acquired the Esquimalt and Nanaimo Railway, which still operates under that name, extending it north from Nanaimo to Alberni on the west coast of the island, and to Courtenay, thus coming very close to the point where the bridge might have been. This will never be built now, at any rate for railway purposes, though just conceivably for a road ; optimism as to the latter still lingers in some quarters; the road from Victoria " up-island " is termed on occasion part of the " Trans-Canada Highway ! "§

Coming now to an outline of this diesel rolling-stock in operation, as experienced by the writer recently on a journey across the continent from Victoria to Montreal, it is appropriate that this should begin on the Esquimalt and Nanaimo Railway, Vancouver Island, with the Budd R.D.C. " Dayliner " (Fig. 10), the latest passenger equipment on this pioneer line. For pioneer it was, the first section of it having been built nearly a century ago—in 1863 to be exact—to handle coal from the Dunsmuir mines at Wellington to the wharf at Nanaimo, so it actually antedates the transcontinental C.P.R. by over twenty years. During this period traction power has ranged the gamut from wood-fired steam locomotives, coal and oil firing following, until steam disappeared altogether in 1949 ; then came diesel-electric machines, and now even these have been displaced from passenger service, and the R.D.C. reigns in their stead. Personally, I have known this fascinating little line for nearly fifty years, and have seen most of these changes take place. It was on this railway that the Canadian Pacific traction metamorphosis began ; in fact I believe the E. and N. was the first line in North America to be completely " dieselised." The conversion was inaugurated in 1948, when a Baldwin 0–4/4–0 1000 h.p. diesel-electric locomotive began trials on the railway, which were so successful that the following year all the steam locomotives, twenty-two in number, were withdrawn, thirteen diesels taking their place. This baker's dozen handled all services, both passenger and freight, until recently, when a Budd R.D.C. was introduced to take care of the former, proving both faster and more economical. The railcar makes a daily round trip between Victoria and Courtenay, 280 miles, during which it is conceivable—though not likely—that some fifty-six stops might be called for, as the majority would be at " flag " stations (Anglicé, halts), some of which would probably be by-passed. Such an exacting schedule would be beyond the capacity of a diesel-electric locomotive hauling several cars, passenger and express (parcels), but the Budd car manages it without difficulty, by virtue of a higher permissible speed and far more rapid acceleration and deceleration. Just as the 1000 h.p. diesels showed to advantage over the old steam locomotives, so does the R.D.C. score over the heavier type where passenger services are concerned ; freights are of course still handled by the latter machines. Thus within a decade or so is seen epitomised on the E. and N. what has taken place all over the country on secondary lines—and I imagine in England too—the change-over from (1) steam, through (2) diesel-electric, to finally (3) rail-car. The transition has come about far more quickly in Canada than in England, though less so than in the States, and it is complete. Neither of the Canadian railways now has any steam locomotives in service—to be pedantically correct, the C.P.R. has one, in the Prairie region, where it is required to supply steam to a Lidgerwood ballast spreader in work train operation ; the sole survivor.

Last December, returning from England through Montreal, I inquired whether there were any steam-powered trains working out of Windsor Station, to be told there was one on the Rigaud run, a mere 40 miles, and I made a point of seeing it leave. It was headed by one of my favourite class, on which I have ridden many thousands of miles between Montreal and Vancouver, always with pleasure—a " Royal Hudson," " 2800 " class, 4–6–4 (Fig. 11). My heart went with it, and my body would have done the same if I had had time to make the necessary arrangements, but I was leaving for the west in a few hours, so it could not be managed, to my lasting regret ; it is probable I shall never see a " 2800 " again,‖ still less travel on one. Instead, no doubt I shall see many diesels in years to come, but when in due course they in turn are ousted by some other form of motive power, which will certainly be the case, I shall fail to squeeze out a single tear. To me, a diesel is a clever piece of machinery, and its good qualities are at once acknowledged ; it has many advantages, and is well worth study, but I cannot conjure up a spark of affection for it. It has no individuality—no soul, in fact—it is a robot ! An electric locomotive is even worse, requiring constant transfusions before it will even come to life at all ! Respect, interest, even some admiration—all these it is conceivable I might feel when contemplating a " Deltic"¶ or No. 9004, S.N.C.F. electric, but affection—*c'est impossible !* That is reserved for a Stanier or Chapelon " Pacific," and they receive it in full measure.

(To be continued.)

§ Ripple Rock, a jagged fang lurking just below the surface of Seymour Narrows, a 10-knot current adding to the danger of navigation, was deemed an ideal footing for a bridge, and any suggestion for its removal was anathema, despite the fact that it had brought many a tall ship to destruction. So there it remained, first discovered no doubt by Vancouver on his passage through the Narrows in 1792, threatened but inviolate, until a couple of years ago, when it was blown up by a method described in this journal at the time. Briefly, a tunnel was driven from the adjacent island to the base of the rock, then upwards to the crown, where an enormous charge of T.N.T. was placed, the explosion being of sufficient magnitude to be registered on distant seismograph., rivalling in effect the underground nuclear tests that the world is squabbling over at the moment, and will no doubt be plagued with in the near future. The top of Ripple Rock was shattered in a cataclysmic blast, disintegrated, and the treacherous obstruction at long last removed.

‖ No. 2850 is the " Royal Engine," which hauled the Royal train across Canada in 1939, when the late King and the Queen Mother toured the country. The picture shows it carrying the Royal Arms in front of the smokebox, and the Crown on the running-board. I rode No. 2850 from Fort William to Winnipeg in 1940 and again in 1941, thus " sitting in the Seat of the Mighty " for the only time in my life. His Majesty was said to have driven No. 2850 some distance west of Fort William. This engine is now scrapped, along with all the other seventy of the class. The chief dimensions are : cylinders 22in by 30in.; driving wheels 6ft 3in.; weight on drivers 81 tons ; weight of engine 153 tons; of tender 118 tons ; total 271 tons. Heating surface tubes and flues 3465 square feet ; firebox 288 square feet ; arch tubes 38 square feet ; superheater 1542 square feet ; total 5333 square feet ; grate area 80·8 square feet ; oil-fired, steam pressure 275 lb. Tractive effort : main cylinders 45,390 lb ; booster 12,000 lb ; water 12,000 gallons ; oil 4100 gallons. No dome ; dry pipe and steam drier. Multiple throttle, " Elesco" feed-water heater, Hancock exhaust steam injector, Walschaerts valve gear engine and trailer truck axles roller bearings.

¶ I have " contemplated " a " Deltic," the original one, and was satisfied. Externally it looked much like other diesels ; I am aware it is not so internally ; a clever machine—I was inclined to think somewhat too clever, but I must be wrong, as I understand ten more have been ordered. Seen in a station the most impressive thing about it was the noise ; the average British diesel engine does seem more noisy than its transatlantic cousins. But probably an engine with seventy-two cylinders cannot help being noisy. Yes, the " Deltic " interested me, but made no particular appeal, lacking individuality, like all diesels. Even S.N.C.F. No. 9004 fails to rouse affection in me, and I have ridden that, from Paris to Le Mans, last year—may I remind the reader that this is the electric locomotive that reached 206 m.p.h. recently ; I could not help admiring and respecting it, alike for its record performance and perfect behaviour when I was in its cab travelling at 80 m.p.h. But I could not feel the glow that comes over me when I look at, or ride, say, that superb four-cylinder compound 4–6–4 " U1 " or a Chapelon " P " 4–8–2, surely the last word in express locomotive design, whose like we shall never see again. I apologise to No. 9004, but there was not the same reaction—in effect, she impressed me as being equivalent to the last word in trams.

Technical Reports

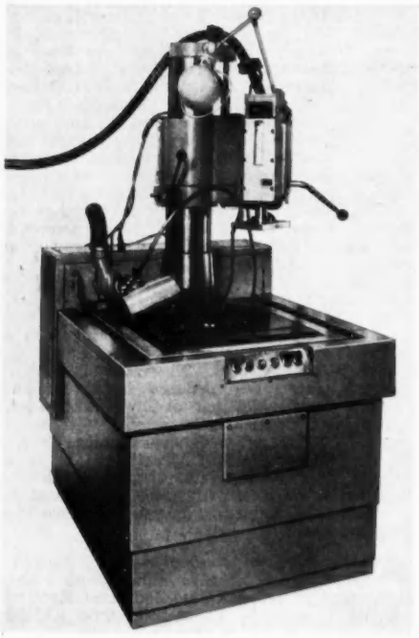
An Investigation of the Stress Distribution in the Anchorage Zones of Post-Tensioned Concrete Members. By J. Zielinski, Dr.Eng., and R. E. Rowe, M.A., A.M.I.C.E. Research Report No. 9. Cement and Concrete Association, 52, Grosvenor Gardens, London, S.W.1. Free.—Existing theoretical and experimental work related to the problem of the stress distribution within the anchorage zones of prestressed concrete beams is reviewed and the considerable differences between the various theories are emphasised. Guided by the anomalies found in this review, the authors planned an extensive series of tests, the results of which could be compared with those predicted by the theories and could be used as empirical data for design. The tests were planned in two stages, the first to deal with the problem of individual end-blocks subjected to single, symmetrically placed, concentrated loads, and the second to deal with the interaction effects when numbers of concentrated forces act on a single end-block of varying cross section. This report is concerned only with the first stage. The variables studied included the ratio of the loaded area to the cross-sectional area, the type of anchorage (whether embedded or external), the effect of ducts, and the percentage and form of the reinforcement. The results obtained are compared with those predicted by the existing theories : the theories due to Guyon and Magnel underestimate the maximum experimental tensile stresses by a percentage varying between 160 and 280 for various ratios of loaded area to cross-sectional area. An empirical method, based upon the experimental results obtained, is suggested for determining the total tensile force and its distribution in an end block.

A Diode-Operated Decimal-to-Binary Converter for a Tape Punch. N.E.L. Fluids Note No. 3. Department of Scientific and Industrial Research, National Engineering Laboratory, East Kilbride, Glasgow.—A device to permit the punching of serialised decimal information in binary-coded decimal form on a seven-hole paper tape punch is described. For this application the information is received in a form suitable for operation of a solenoid-controlled electric typewriter. For punch operation each digit has to be converted into its equivalent binary form, the " parity " digit added where necessary, and then applied to set the knives of the paper tape punch, which is actuated by a trip signal two milliseconds later. Attempts made to meet the requirements with relays attained some success, but variations in contact closure time occasionally resulted in under-punching. In the device described the decimal information is encoded by a matrix of silicon junction diodes, and a high-speed relay is included to give the necessary delay before tripping the motorised punch. Provision is made for manual control if required.

Spark Erosion Machines

A NEW company, Solar Weld Languepin, Ltd., Fulledge Works, Burnley, Lancs., has been formed to market the range of spark erosion machines made in France by La Soudure Electrique Languepin. Initially the company is to sell, service and provide technical advice on the machines which it is proposed to build in this country at some later date for the home and Commonwealth markets. Three typical machines of the range recently demonstrated included the "Seleromat A," the "Seleromat B" and a smaller bench-mounted "Seleromic" equipment.

The "Seleromat A," shown in our illustration, has its erosion head adjustably mounted on an articulated arm which can be swung round on the pillar to give clear unobstructed access to the whole area of the 20in by 25in work table. The "B" machine



"Seleromat A" spark erosion machine having its erosion head mounted on an articulated arm. For roughing work this machine has an erosion rate of 1000 cubic millimetres per minute

is generally similar in all respects except that its head is supported on co-ordinate slides to facilitate precise setting of the electrode in respect to components on the table. Each machine is served by a separately mounted spark generator and a filtration equipment for the removal of micro-solids from the dielectric medium. A tank incorporated in the welded steel base of the machine takes 100 gallons of dielectric fluid which is circulated by an integral pumping set. The level of dielectric is automatically maintained constant in the tank, which is raised by power to submerse the table, electrode and workpiece during the operating cycle.

On the "A" machine the arm on which the electrode carrier and servohead assembly is mounted has a vertical screw-operated traverse of 24in on its pillar. The arm can be swung horizontally to any required position and locked by quick-action clamps, final horizontal adjustment of the arm for electrode positioning being made by a fine setting screw. The servohead is mounted in vee slides at the end of the arm and has the electrode carrier fixed to its base. This head has a vertical travel of 4in and its motion is derived from a split-field d.c. motor driving a leadscrew through a reduction box. Its automatic down-feed is controlled by electrical trips and the depth required can be preset on a micrometer scale to increments of 0·001in. A vibrator can be interposed between the electrically insulated electrode carrier and the servohead base, and this vibrator, with a vertical movement of 0·0005in at 50 c/s, provides mechanical pulsation to assist in flushing the eroded debris from the discharge area.

The spark discharge generator used for the "Seleromat A" and "B" machines derives its power from a three-phase a.c. supply of 440V at 50 cycles. With this generator and using a 2·75 diameter copper electrode with a steel specimen treated to ~56 Rockwell C a machine has the following capacities at its four settings :

Setting	Erosion rate	Surface finish	Tolerance
Roughing ...	1000 cu. mm/min	50 microns	0·004in
Semi-roughing	140 cu. mm/min	18 microns	0·003in
Finish	9 cu. mm/min	5 microns	0·001in
Super-finish ...	2 cu. mm/min	2 microns	0·0003in

Within the generator equipment alternating current is obtained from a single-phase alternator, the output voltage of which is adjusted to a predetermined value and fed into a bridge rectifier circuit. Positive pulses from the rectifier bridge are used to charge one of four banks of capacitors which discharge between the electrode and the workpiece. The single-phase alternator is driven by a three-phase synchronous motor controlled by a built-in star-delta starter. The full wave bridge rectifier has a "warm-up" delay switch.

A push-pull servo amplifier in the cabinet maintains a constant spark gap between electrode and workpiece, and controls the split-field d.c. motor in the erosion head of the machine. The voltage across the spark gap is integrated and compared with a reference voltage, and the error is amplified and fed directly to the servo-motor to make the necessary corrections to the gap width. This servo-control amplifier is housed in a drawer on the front of the generator cabinet and the drawer carries indicator lights showing that the alternator excitation circuit is functioning.

The rate of erosion is selected by a four-position heavy-duty switch, the control handle of which has settings marked "roughing," "semi-roughing," "finishing" and "super-finishing." A small pilot switch working in conjunction with the heavy-duty switch open-circuits the d.c. excitation supply to the alternator field and allows the range to be changed without touching any other controls. This arrangement ensures that the switch is always operated when the passage of current has ceased, and as a result very little contact wear occurs.

Another arrangement allows control of the d.c. field excitation of the alternator and gives a continuous control of the erosion rate for each value of output capacitor with a consequent continuous control of the erosion rate over the entire operating range. The field excitation control is positioned at the front of the main panel of the equipment and other controls indicating machine functioning are clear to the operator.

Automatic stops can be set to halt the movement of the servohead automatically at any predetermined depth of penetration without switching off the complete generator equipment. Alternatively, the controls can be set to switch off the whole installation at a predetermined depth so that the equipment can be left running without attention for considerable lengths of time.

The high rates of metal removal by the machines require a copious supply of clean dielectric fluid to ensure good surface finish

Spark discharge generator for erosion machine

on the work. Mechanical filtration of the fluid at 11 gallons per hour is effected in the filtration equipment, which is separate from the generator and the spark erosion machine. The filter, which is adjusted to remove particles down to 1 micron in size, incorporates nineteen built-in paper disc cylindrical elements.

The accumulation of solid particles on the exterior of the filter element is removed by blowing compressed air outwards through the element from the centre. The necessary frequency of element cleaning is dependent on the amount of heavy-rate erosion work undertaken, but on single shift working it need not exceed twice per working week. Deposits removed from the filter pack are collected in a built-in tray. One of two pumps in the filtering equipment is used for scavenging from the erosion machine and the other for returning clean dielectric to the worktable.

ENGINE OIL FILTERS.—A warning has been issued by Leyland Motors, Ltd., and Albion Motors, Ltd., regarding a proprietary engine lubricating oil filter element which is now advertised as being designed to replace the cloth filter element fitted to Leyland and Albion engines. They state that it may be inferred from this advertisement that the paper filter element has received their approval but this is not the case. In consequence, any resulting damage when using filter elements other than the recommended cloth type cannot be considered by Leyland or Albion in respect of service claims.

INSTITUTE OF THE MOTOR INDUSTRY.—The annual dinner of the Institute of the Motor Industry (Inc.) will be held at the Park Lane Hotel, London, W.1., on Thursday, April 13, 1961. The guest of honour will be Field-Marshal Viscount Montgomery of Alamein, K.G., G.C.B.

THE ENGINEER

Technical Contributors Section

FEBRUARY, 1961

Torsional Stiffness of Non-Circular Shafts

By D. R. AXELRAD, Dipl.-Ing., A.M.I.Mech.E., A.M.I.E. (Aust.)*

Recently the application of shafts having cross sections with multi-symmetrical curved boundaries in place of the conventional splined shafts has become significant in machine design. It is apparent that the presence of keyways or splines in circular shaft-hub connections causes a reduction of strength of such couplings. By employing non-circular shaft-hub connections of the type indicated in Fig. 1 (*b*), *stress concentration can be either greatly reduced or even eliminated. Although investigations on the torsional properties of the shapes in Fig.* 1 (*b*)–(*g*) *have been carried out with some of the results given in reference* 1, *the present article is mainly concerned with the properties of the cross sections* (*c*)–(*d*) *of Fig.* 1. *These sections are based on the shape of an equilateral triangle and, owing to the prevailing symmetry, have advantageous mechanical and dynamical properties.*

Generation and Geometrical Properties of Shapes (*c*) (*d*)

NON-CIRCULAR shaft profiles of the type mentioned above can be conveniently generated by a continuous grinding process. One particular grinding machine, known as the " Polygon-Manuhrin " machine employs for this purpose an oscillating grinding wheel whilst the workpiece performs a uniform rotation. The oscillating motion of the wheel is achieved by means of a motor-driven eccentric, a horizontal and vertical sliding member over a multiplying lever arrangement. Thus, two sinusoidal motions are induced in directions perpendicular to each other. The horizontal component of the two motions determines the " throw " of the workpiece (i.e. the difference between the inscribed and circumscribed circle diameters), whilst the vertical component effects the placing of the grinding wheel at the instantaneous position of the normal to the boundary curve to be generated. This aspect is of considerable advantage since normal wheel wear does not affect the generation of the contour. The process is equally applicable to external and internal grinding. In the case of four-lobed or square sections, however, internal grinding is unsuitable due to the small internal radius occurring along the contour. Since the driving eccentric in this machine is designed so as to permit a continuous adjustment of the throw from zero to a maximum (within the capacity of the machine), a great variety of boundary curves can be produced.

If the workpiece and eccentric for instance have the same speed and the throw is imparted in the ratio 1 : 1, an eccentric will be generated. Changing this ratio to 2 : 1 so that the grinding wheel performs two revolutions per one revolution of the workpiece a two-lobed shape (elliptical cross section) is obtained. Similarly, using the ratios 3 : 1 or 4 : 1 results in generating either a three- or four-lobed profile. In each case the final shape of the cross section will depend on the magnitude of the throw. The influence of the variation of throw on the generated shape is easily noticed by considering the three-lobed section of Fig. 1 (*c*), (*d*). If the throw becomes smaller the boundary curve tends to become a circle. If the throw is increased the boundary curve will become more acute, resulting ultimately in the shape with three sharp corners (Fig. 1 (*c*)). Hence by varying the throw it is possible to achieve the correct pressure angle between shaft and hub. This is significant for the resistance of the coupling to the applied torque and also for the sliding property of the hub on the shaft. Since the generated contour is a continuous analytical curve a relation between the eccentricity e of the driving eccentric, the circumscribed circle diameter D, the inscribed circle diameter d and the mean diameter of the profile D_m will exist. This relation together with the value of the maximum pressure angle is indicated in Fig. 1 (*d*). It may be noticed that the radius of curvature r at the corners of the boundary curve influences the maximum wheel diameter for internal grinding. Shapes with small corner radii are usually employed for fixed couplings or drive fit. A sliding fit is obtained when the maximum pressure angle is large, but at least twice the friction angle to be considered for each component of the coupling. A proper sliding fit can also be achieved by generating a profile with discontinued contact surfaces as indicated in Fig. 1 (*g*). For this purpose a boundary curve of larger throw and greater diameter D over a given circular shaft diameter must be generated so that three cylindrical and three arc sectors are obtained alternately.

Three-lobed sections produced in the above-mentioned manner have larger cross-sectional areas and moments of inertia than the corresponding splined shaft sections. This is indicated in Fig. 2, showing the plot of cross-sectional areas against diameter D for a rounded-edge type section of an inscribed circle diameter equal to the root diameter of a six-splined section.

Torsional Stiffness of Non-Circular Sections (General Theory)

It is well known that transverse sections of non-circular shafts subjected to pure torsion do not remain plane during twisting but become warped. Under the usual assumption of theoretical stress analysis, that all sections of the shaft warp in the same manner and if x, y, z represent the rectangular co-ordinates of a point in any section, the displacements of this point can be expressed by :

$$u=\theta zy$$
$$v=\theta zx$$
$$w=\theta\phi\,(x,y) \quad . \quad . \quad . \quad . \quad (1)$$

where θ denotes the angle of twist per unit length of shaft ϕ, some function of the variables (x,y) and z being identical in direction with the shaft axis. The function ϕ must be determined so as to satisfy the equilibrium, compatibility and boundary

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Technical Contributors Section (*continued*)

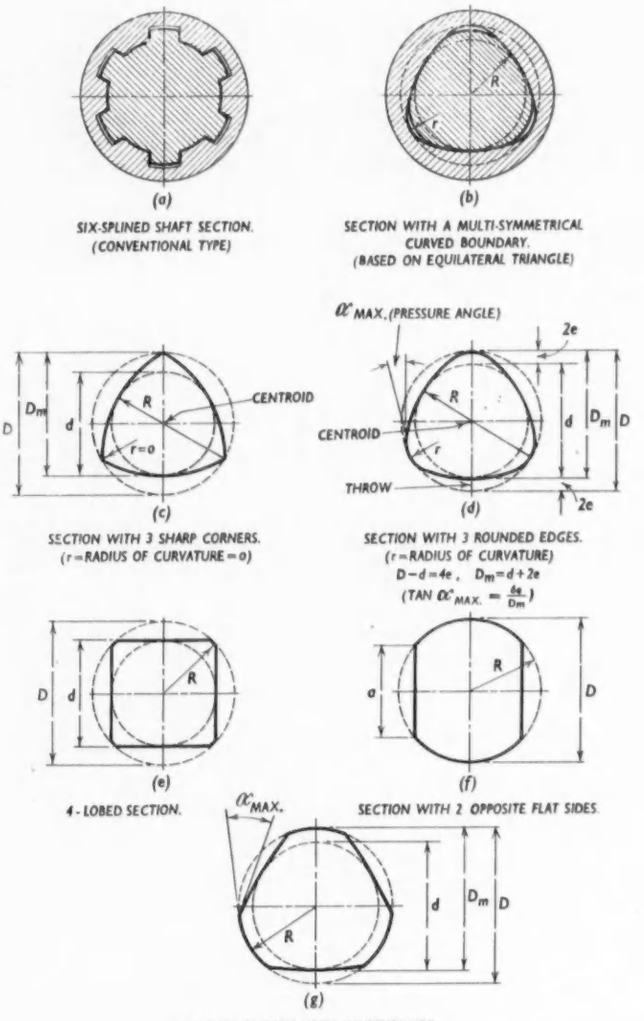


Fig. 1—Non-circular shaft profiles

conditions. The corresponding stress components are then :

$$\tau_{zx}=G\theta\left\{\frac{\partial\phi}{\partial x}-y\right\}$$

$$\tau_{zy}=G\theta\left\{\frac{\partial\phi}{\partial y}+x\right\}$$

$$\tau_{xy}=\tau_{xx}=\tau_{yy}=\tau_{zz}=0 \quad . \; . \; . \quad (2)$$

in which G represents the modulus of elasticity in shear of the material. If it is further assumed that no body forces are acting, it is seen by substituting equation (2) into the equilibrium conditions that the latter are satisfied, if the function ϕ is analytic throughout the region of the section. It will then also satisfy the condition :

$$\nabla^2\phi\equiv\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0 \quad . \; . \; . \; . \quad (3)$$

throughout the region R and on the boundary L of the section. The above stress distribution, however, is equivalent to a torsional couple applied at distance $z=L$ (the shaft being fixed at $z=0$) and the resultant force acting on the end of the shaft vanishes. The magnitude of the couple is given by its moment vector :

$$M_z=G\theta\iint_R\{x\tau_{zy}-y\tau_{zx}\}dxdy \quad . \quad (4\,a)$$

This expression can also be written by using Green's theorem to the integral on the right-hand side as follows :

$$M_z=G\theta\iint_R\left\{(x^2+y^2)+\left(\frac{\partial\phi}{\partial x}x-\frac{\partial\phi}{\partial y}y\right)\right\}dxdy$$

$$. \; . \; . \; . \quad (4\,b)$$

from which it may be seen that the value of the integral depends on the function $\phi\,(x,y)$ and hence from the shape of the cross section. The product of the integral value times the modulus of elasticity in shear is commonly referred to as the torsional stiffness of the profile, namely :

$$S=G\left[\iint_R(x^2+y^2)\,dxdy+\iint_R\left(x\frac{\partial\phi}{\partial x}-y\frac{\partial\phi}{\partial y}\right)dxdy\right]$$

$$=G[I+S_0] \quad . \; . \; . \; . \; . \; . \; . \quad (5)$$

The evaluation of the double integrals, however, by using the torsion function $\phi\,(x,y)$ leads in most cases to considerable computational work. It is more convenient to determine the stiffness of the shapes (Fig. 1 (*c*)–(*g*) by employing the " complex torsion function " obtained from a conformal map of the section on to the unit circle. This approach to the determination of the torsional properties of non-circular profiles is due to N. I. Mushkelisvili.[2] A more detailed treatment of the stress analysis of the shape Fig 1 (*d*) based on this theory and in particular the method employed to obtain an approximate map of the profile has already been given in reference 3. The method will also be used in the following for determining the torsional stiffness of the shapes Fig. 1 (*c*) (*d*).

It is readily seen that if n denotes the exterior normal to the boundary curve L at any point, dL an elemental arc length of this curve in direction of the tangential shearing stress, the boundary condition will be given by :

$$\frac{d\phi}{dn}=\frac{\partial\phi}{\partial x}\cdot\frac{dy}{dL}-\frac{\partial\phi}{\partial y}\cdot\frac{dx}{dL} \quad . \; . \; . \quad (6)$$

Using the conjugate function $\psi\,(x,y)$ to the function $\phi\,(x,y)$ where both functions are related by :

$$\frac{\partial\phi}{\partial x}=\frac{\psi\partial}{\partial y},\ \frac{\partial\phi}{\partial y}=-\frac{\partial\psi}{\partial x} \quad . \; . \; . \; . \quad (7)$$

yields by combining (6) and (7) :

$$\frac{d\phi}{dn}=\frac{\partial\psi}{\partial x}\cdot\frac{dx}{dL}+\frac{\partial\psi}{\partial y}\cdot\frac{dy}{dL}\equiv\frac{d\psi}{dL} \quad . \; . \quad (8)$$

Hence the boundary condition of $\phi\,(x,y)$ can also be formulated in terms of $\psi\,(x,y)$. The complex torsion function is now obtained as :

$$F(z)=\phi+i\psi \quad . \; . \; . \; . \quad (9)$$

where z is the complex variable. Since the regions of the shapes considered are simply connected, they can be mapped conformally on to the unit circle with boundary γ in the ξ plane ($|\xi|\leqq|$) and hence :

$$z=x+iy=w(\xi)$$

$$\bar{z}=x-iy=\bar{w}(\xi) \quad . \; . \; . \quad (10)$$

where $w(\xi)$ represents the mapping function of the region. Expression (9) becomes thus :

$$F(z)=\phi+i\psi=F[w(\xi)]=f(\xi) \quad . \; . \quad (11)$$

This function is readily determined, since the boundary value of its imaginary part is known. Thus using expression (8) it follows upon integration that

$$\psi=\tfrac{1}{2}(x^2+y^2)+C$$

in which the arbitrary constant C may be omitted, since it has no effect on the state of stress. Hence the boundary condition is also by observing (10) :

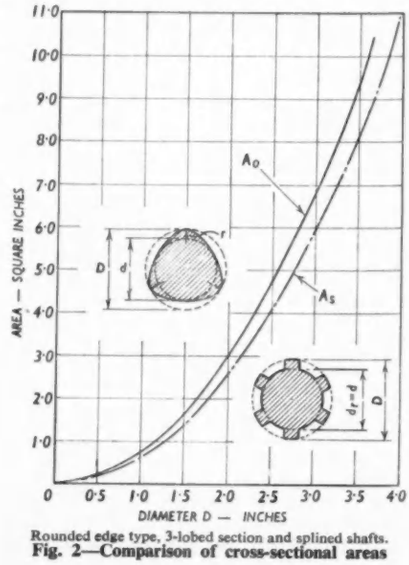
$$\psi=\tfrac{1}{2}(x^2+y^2)=\tfrac{1}{2}z\bar{z}$$

or

$$\psi=\tfrac{1}{2}w(\xi)\,\bar{w}(\xi).$$

If $\sigma=e^{i\theta}$, $\bar{\sigma}=e^{-i\theta}$ denote the co-ordinates of any point on the unit circle, the boundary condition on γ will finally take the form :

$$\psi=\tfrac{1}{2}w(\sigma)\,\bar{w}(\sigma) \quad . \; . \; . \; . \quad (12)$$



Rounded edge type, 3-lobed section and splined shafts.

Fig. 2—Comparison of cross-sectional areas

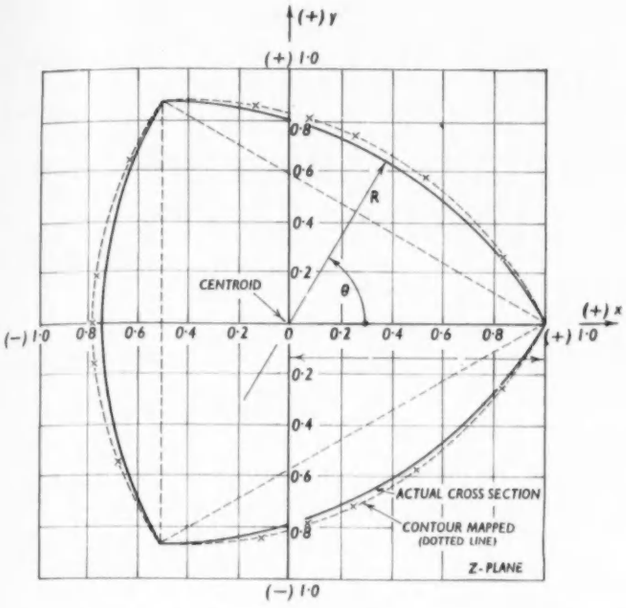


Fig. 3—Map of three-lobed section (sharp-cornered Fig. 1c)

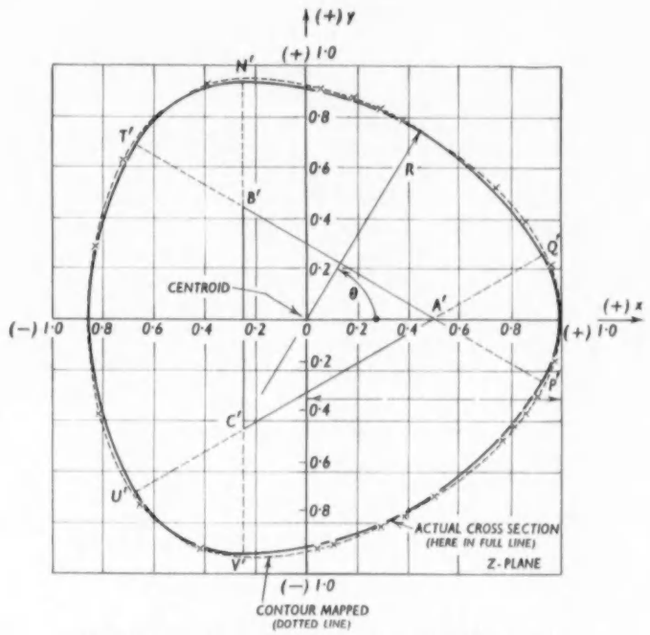


Fig. 4—Map of three-lobed section (rounded edge Fig. 1d)

Applying now the first theorem of the theory of functions, then the complex torsion function in terms of the contour integral (*on* γ) becomes :

$$f(\xi)=\frac{1}{2\pi i}\oint_{\gamma}\frac{w(\sigma)\,\bar{w}(\sigma)}{\sigma-\xi}d\sigma=\phi+i\psi=F[w(\xi)]\ . \quad (13)$$

so that $f(\xi)$ will be obtained, if the mapping function $w(\xi)$ and its corresponding boundary values $w(\sigma)$, $\bar{w}(\sigma)$ are determined. The Cauchy integral (13) can be calculated by means of the residue theorem from the theory of a complex variable and leads to a function in ξ, so that finally the solution of the problem can be expressed in terms of elementary functions.

In order to find the mapping function $z=w(\xi)$ that maps in an approximate manner the given cross section in the z plane on to the unit circle in the ξ plane any polynomial of the form

$$w(\xi)=p_0+p_1\xi+p_2\xi^2+\ldots\ldots p_n\xi^n \quad (14)$$

may be used. The condition required for a conformal map, however, is that $w^1(\xi)\neq 0$ inside the region bounded by the unit circle. A method often used to obtain such a polynomial is to approximate the given contours L in the z plane by a polygon and transform the latter on to the unit circle by aid of a Schwartz-Christoffel formula, namely :

$$z=w(\xi)=A\int_0^{\xi}(\xi-\xi_1)^{\alpha_1-1}\ (\xi-\xi_2)^{\alpha_2}$$
$$(\xi-\xi_n)^{\alpha_n-1}d\xi+B\ .\ .\ .\ .\ . \quad (15)$$

in which the ξ_i represent points on the boundary ξ of the unit circle that correspond to the vertices of the polygon in the z plane and $\alpha i\pi$ the exterior angles at these vertices. The constant A may be used to adjust the size and position of the polygon in relation to the reference axes. The integration constant B may be disregarded, since it is immaterial for the solution of the problem.

By using the above described method in dealing with the profiles of Fig. 1 (*c*)(*d*) it has been possible to construct the maps of these sections as indicated in Figs. 3 and 4 respectively. For the purpose of these plots parametric equations of the mapping functions were employed and the contours drawn at intervals of 5 deg. in θ (dotted lines in graphs). Further the constant A of expression (15) was chosen so that $z=0$ corresponds to $\xi=0$ and the radius of the circumscribed circle of the curvilinear triangle is equal to a constant ρ.

It may be noticed from the diagrams that the errors involved are of little significance for engineering purposes. In particular the plot of the rounded-edge section approximates very nearly the actual boundary curve.

In order to evaluate the torsional stiffness of the profiles (*c*) (*d*) it will be necessary to formulate the corresponding expression (5) in terms of the derived mapping function and its boundary values $w(\sigma)$, $\bar{w}(\sigma)$. Hence considering the quantities I,S_0 separately the first will be determined as follows :

$$I=\iint_R(x^2+y^2)\,dx\,dy=\iint_R\left[\frac{\partial(x^2_1y)}{\partial x}+\frac{\partial\,(y^2_1x)}{\partial y}\right]dx\,dy$$
$$=-\oint_L xy\{xdx-ydy\}$$

but

$$x=\frac{z+\bar{z}}{2}\ ,\quad y=\frac{z-\bar{z}}{2i}$$

Hence

$$I=\frac{1}{8i}\oint_L\{z^2-\bar{z}^2\}\,(zdz-\bar{z}d\bar{z}).$$

It is readily seen, however, that the integrals

$$\int_L z^2dz,\ \int_L\bar{z}^2\,d\bar{z}$$

are both zero valued and thus

$$I=\frac{1}{4i}\oint_L z\bar{z}^2\,dz=\frac{1}{4i}\oint_{\gamma}[\bar{w}^2(\sigma)]\,w(\sigma)\,d\,\{w(\sigma)\}$$
$$\ .\ .\ .\ .\ . \quad (16a)$$

In a similar manner the second quantity S_0 can be formulated as :

$$S_0=\iint_R\left\{x\frac{\partial\phi}{\partial y}-y\frac{\partial\phi}{\partial x}\right\}dx\,dy$$
$$=-\oint_L\phi\{xdx+ydy\}=-\oint_L\phi d\left\{\frac{r^2}{2}\right\}$$

where $r^2=x^2+y^2$ and on boundary γ;

$$r=z\bar{z}=w(\sigma)\,\bar{w}(\sigma)$$
$$\phi=\tfrac{1}{2}\{f(\sigma)+\bar{f}(\sigma)\}$$

Hence

$$\oint_L\phi\{xdx+ydy\}=-\tfrac{1}{2}\oint_{\gamma}\phi d\,\{z\bar{z}\}$$

and

$$S_0=-\tfrac{1}{4}\oint_{\gamma}\{f(\sigma)+\bar{f}(\sigma)\}\,d\,\{w(\sigma)\,\bar{w}(\sigma)\}\ .\ .\ .\ (16b)$$

Combining (16*a*) and 16*b*) yields therefore an expression, which by multiplying it by G gives finally the torsional stiffness of the profile.

Numerical Values of the Torsional Stiffness

Using the mapping functions of the profiles and substituting the corresponding boundary values into the above expressions 16 (*a*, *b*) yields upon computation of the contour integrals the quantities I, S_0. In the case of the profile having three sharp corners (Fig. 1 (*c*) the theoretical value of the stiffness is obtained as follows :

$$(I)_s=[0\cdot6141]\,\frac{\pi}{2}\cdot\rho^4$$

$$(S_0)_s=-[0\cdot0529]\,\frac{\pi}{2}\cdot\rho^4$$

and

$$S_s=G[I+S_0]=[0\cdot5612]\,G\frac{\pi}{2}\rho^4\ .\ .\ .\ (17)$$

in which the subscript s refers to the sharp cornered section. However, in order to compare the torsional stiffness of this shape to that of a circular shaft, it is necessary to compute the area of the mapped cross section. The latter can be obtained from the parametric equations of the mapping function and yields after computation the numerical value of $0\cdot7723\pi\rho^2$. Since the cross-sectional area bounded by the unit circle is equal to π it follows that $\rho^4=1\cdot6765$.

Hence, denoting by $\Delta=G\pi/2$ the torsional stiffness of the circular shaft bounded by the unit circle, the stiffness of the profile considered from (17) will also be :

$$S_s=\frac{G\pi}{2}[0\cdot941]=[0\cdot941]\,.\,\Delta\ .\ .\ (18)$$

In a similar manner computations for the case of a rounded-edge shaft (Fig. 1 (*d*)) yield :

$$(I)_R=[0\cdot7561]\,.\,\frac{\pi}{2}\rho^4$$

$$(S_0)_R=-[0\cdot0237]\,.\,\frac{\pi}{2}\rho^4$$

and

$$S_R=G[I+S_0]=[0\cdot732]\,.\,\frac{\pi}{2}\rho^4.\ .\ .\ (19)$$

where the subscript R refers to the rounded edge type shaft. Again choosing the radius ρ so that the area of the cross-section equals π the stiffness is finally given by :

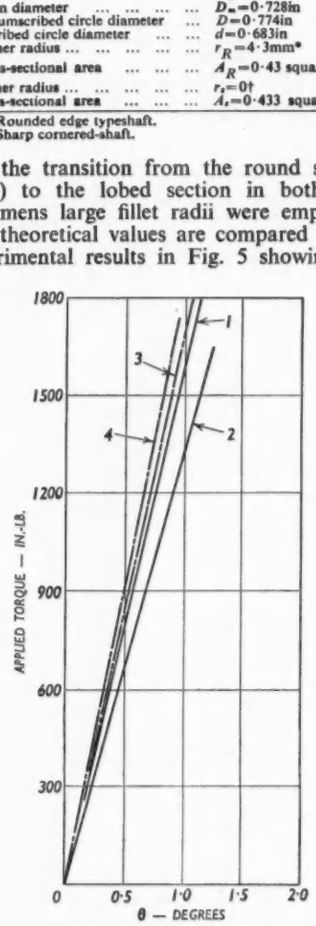
$$S_R=[0\cdot978]\,.\,\frac{G\pi}{2}=[0\cdot978]\,.\,\Delta \quad . \quad . \quad (20)$$

In order to verify experimentally the above theoretical stiffness values of the profiles, a series of torsion tests on mild steel bars ($G\approx12\times10^6$ lb per square inch) were carried out. The test pieces were of the following dimensions :

Overall length	$L=8\cdot5$in
Gauge length	$L_G=3\cdot3125$in
Mean diameter	$D_m=0\cdot728$in
Circumscribed circle diameter ...	$D=0\cdot774$in
Inscribed circle diameter	$d=0\cdot683$in
Corner radius	$r_R=4\cdot3$mm*
Cross-sectional area	$A_R=0\cdot43$ square inch
Corner radius	$r_s=0$†
Cross-sectional area	$A_s=0\cdot433$ square inch†

* Rounded edge typeshaft.
† Sharp cornered-shaft.

For the transition from the round section (grip) to the lobed section in both type specimens large fillet radii were employed. The theoretical values are compared to the experimental results in Fig. 5 showing the



Rounded Edge Type (Fig. 1*d*) (1) Experimental result. (3) Theoretical values.
Sharp Cornered Type (Fig. 1*c*) (2) Experimental result. (4) Theoretical values.

Fig. 5—Comparison of test results to the theoretical torsional stiffness of profiles Fig. 1, *c*, *d*

applied torques versus angles of twist in degrees. The experimental stiffness values have been derived from the corresponding torque-twist diagrams (within the elastic limit of the material) of the test bars. It may be seen that a fairly good agreement between theoretical and experimental values is obtained particularly for the rounded-edge section. This is to be expected since this cross-section is much nearer to the circular form than the sharp cornered profile.

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Calibrating A.C. Ammeters of Widely Differing Ranges

By D. KARO, Dr.Eng., Ph.D., Dipl.Eng., M.I.E.E.*

The author describes a convenient method of calibrating different types of a.c. ammeters against a standard ammeter. The ranges of the calibrated and standard meters may be very different and the method is suitable for a large range of frequencies.

THERE are very few methods of testing and calibrating a.c. ammeters, and the few methods that exist are very much restricted in current range or frequency range, or both.

The use of an a.c. potentiometer is normally restricted to power frequencies, the apparatus required is elaborate and costly, the method is tedious and suffers from the disadvantages common to all potentiometer methods. The use of the elaborate equipment necessary in normal potentiometer methods is certainly not justified when calibrating an ammeter, since in the final analysis the meter is calibrated against a transfer instrument, usually a standard dynamometer ammeter.

The method of direct comparison, that is the method where the same current flows through the standard and the calibrated meter, would be just as satisfactory as a conventional potentiometer method but for the fact that the range of the standard is very restricted. This restricted range requires several expensive standards, and even so the method of direct comparison is not normally possible for the calibration of meters having full-scale deflections ranging from micro-amperes to several amperes ; available standards do not cover such a range of current. Multi-range iron-cored current transformers of known or very small ratio-errors could be used at power frequencies for a certain range of calibrated meters, but hardly for milliampere or microampere meters when calibrated against an a.c. standard. The same considerations apply at frequencies higher than power frequencies, except that perhaps special-core or air-cored transformers could be used. These transformers would of course have to be suitably calibrated to cover a wide range of current. A method where ammeters of almost any f.s.d. reading could be calibrated against normal standard ammeters of a widely different f.s.d. reading would naturally be very useful. This article describes such a method.

Basic Circuit and Principle of the Method

The circuit is shown in Fig. 1. M_1 and M are two mutual inductance standards, the impedances of the secondaries of which are respectively Z_4 and Z_3; Z_1 and Z_2 are a resistor and a standard inductor.

The e.m.f's induced in the secondaries of M_1 and M by the primary current I_p (measured by the ammeter A_p) are in phase opposition. The current I_1 is measured by the meter A_1 ; A_p and A_1 are respectively the standard and the meter being calibrated or vice versa.

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The p.d. of the source is variable. The current in the detector will be zero when

$$-jM_1\omega I_p=(Z_1+Z_2+Z_4)I_1 \quad . \quad . \quad (1a)$$

$$jM\omega I_p=-Z_3I_1 \quad . \quad . \quad . \quad (1b)$$

hence for zero current in the detector,

$$\frac{M-M_1}{M}Z_3=Z_1+Z_4 \quad . \quad . \quad . \quad (2)$$

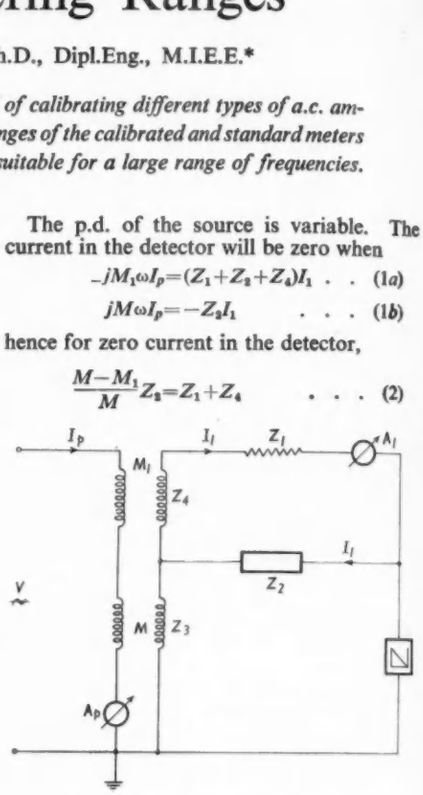

Fig. 1

From (1*b*) it follows that,

$$\frac{I_1}{I_p}=\frac{-jM\omega}{Z_2}=\frac{-jM\omega(R_2-jL_2\omega)}{R_2^2+L_2^2\omega^2}$$

The ratio of magnitudes is,

$$\frac{I_1}{I_p}=-\frac{M\omega}{Z_2}$$

hence,

$$I_1=I_p\frac{M\omega}{Z_2}\ ;\ I_p=I_1\frac{Z_2}{M\omega}$$

Z_4 contains the impedance of A_1, at balance there is no current in Z_3 and the e.m.f. $M\omega I_p$ is balanced by Z_2I_1. Once a single balance is achieved satisfying (1*a*–1*b*), the calibration of the ammeter A_1 (or A_p) can be checked over all of its scale by variation of the current through A_p (or A_1), (varying the voltage v of the source).

$M\omega/Z_2$ can be made equal to a power of ten (or any suitable number) for convenience in calibration.

The calibration of milli-ammeters or even microammeters can easily be made with a normal 0–1A standard ammeter.

Calibration of Ammeters at Audio and Higher Frequencies

Fig. 2 shows the basic circuit with its capacitances to earth. The capacitance C_1 shunts the source, and capacitances C_7 and C_8 shunt the detector ; they do not therefore matter in the balance. The capacitances C_2 and C_4 shunt the primaries of M and M_1

in order to ensure that the same current I_p flows through these primaries; either C_3 or C_4 should be properly adjusted by means of

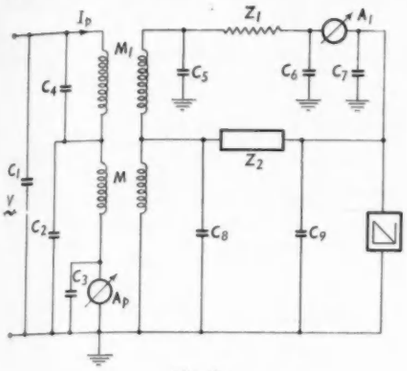

Fig. 2

a suitable small capacitance. The capacitance C_3 shunts the ammeter A_p; it should therefore be as small as possible. The effect of the capacitances C_5 and C_6 on the upper branch of the circuit and on M_1 is immaterial, since when balance is achieved only equation (1*b*) matters as far as the calibration is concerned. Nevertheless C_6 ought to be small not to divert an appreciable current from A_1. The currents through C_5, C_6 and C_8 returning through the secondary of M affect the balance equation (1*b*). If, however, the inductive reactance $L_3\omega$ of Z_3 is much greater than its resistance R_3, and C_6 is small enough, the effect of these capacitances can easily be accounted for.

Let I be the current through Z_3 due to these capacitances, the p.d. across the secondary of M will then be,

$$jM\omega I_p - Z_3 I = \cong jM\omega Ip - jL_3\omega I.$$

The current I passes through an inductance and a capacitance equivalent to C_3, C_5 and C_6; one can write, therefore,

$$jM\omega_p I - jL_3\omega I = jM_e\omega I_p,$$

and the result is an alteration of the mutual inductance. If C_6 is small M can be calibrated to include the effect of C_8 and C_5 if these are known.

The standard A_p (or A_1) have, of course, to be suitable ammeters for the frequency used.

Experimental Verification

Moving-iron, bridge-rectifier and dynamometer ammeters of widely differing f.s.d's were calibrated against a single range dynamometer standard. At audio and higher frequencies, rectifier and hot-junction ammeters were calibrated against a suitably calibrated vacuo-junction ammeter. Once the value of $M\omega/Z_2$ was fixed, the calibrations were easy and quite speedily done. The results, provided the frequency was known, were sufficiently accurate.

Appendix

The parameters of ammeters such as their resistance and inductance may vary with their deflection. The balance may therefore have to be amended during calibration. This variation of the parameters of the ammeter A_p does not however alter the balance; the variation of the parameters of A_1 does affect the balance, but in most cases the effect of this variation is negligible and smaller than the reading error. In any case (1b) need not be affected since Z_2 need not be varied and any correction of the balance can be made by alteration of Z_1.

Balancing Multi-Bearing Machines

By DR. Z. PARSZEWSKI* and DR. P. GROOTENHUIS†

The "on-site" balancing of multi-rotor machines with flexible shafts is considered as an ordered approach requiring a minimum of test runs, as against the general trial and error methods. The method uses influence coefficients to denote the effect of out-of-balance in one rotor upon the motion at some other point. These coefficients can either be calculated from the known details of the machine or determined by experiments as outlined. The method demands only the measurement of total motion at each point requiring isolation, without any regard to phase. Two alternative approaches are given for obtaining the unknown out-of-balance forces in the system. The second approach requires the least number of tests with the machine but involves more computation. Experiments with a multi-disc balancing apparatus with flexibly mounted bearings are described to illustrate the application of the method and to show that a relatively inaccurate measurement of motion at the measuring points does not make the process invalid.

THE balancing "on-site" of complex shaft-systems comprising several rotors and bearing pedestals can be a formidable problem, even though the individual components may have been balanced accurately during manufacture. Misalignment between shafts cannot always be avoided, particularly if some of the components have not been manufactured at the same factory but are assembled as a unit on site for the first time. The final bearing support conditions differ generally from those in the balancing pit. The ultimate location of a steam turbine for example is often over the condenser, but this condition can hardly be reproduced when balancing the rotor in a balancing machine at the works. Modifications to a rotor after balancing, although considered to be not of any serious consequence for the balance of the particular shaft, may have an adverse effect upon the balance of the system as a whole. Furthermore a shaft may have become distorted during transit or assembly. The effect of any one of such changes would only become apparent when the plant was operated for the first time.

Uncontrolled out-of-balance in the system will result in severe dynamic loadings upon the bearing pedestals and foundations, although no particularly serious shaft stresses need be introduced. An "on-site" balancing operation will therefore have as its aim the reduction of bearing pedestal movement to an acceptable level. The conventional approach of balancing by "trial and error" can be very tedious when there are several rotors on a flexible shaft. An ordered approach is outlined for balancing a flexible shaft with any number of rigid rotors and bearings, one of its chief virtues being that only the maximum amplitudes of motion need be measured at selected points when known amounts of unbalance are introduced, without regard to the phase angle between the amplitudes. Not to have to measure any phase relationships is an advantage when a phase indicator cannot be attached to the shaft conveniently or when the necessary electronic apparatus is not readily available. Amplitudes can be measured by any convenient means. Methods[1] requiring phase measurement between the motions of several bearing pedestals require a number of pick-ups, each of which may introduce an unknown phase angle of its own between the actual motion and its output signal.

The dynamic behaviour of flexible rotors including whirling resonances has received much attention (see, e.g. references 2–5) and will not be considered. The method discussed here deals with the final adjustments necessary on site to produce a quietly running plant and is a generalisation of the method described by Parszewski.[6]

Analysis

The principle of the method is to so balance the rotating parts to make nodes at selected measuring points. This will only be effective at speeds different from those whirling speeds which would tend to impose an alternative modal pattern upon the system. But all whirling speeds should be avoided in any case. These measuring points or nodes need not always be the bearing pedestals but could be positions on the casings or foundations where the level of vibration is excessive. Only a limited amount of balancing needs to be carried out to make a node at such a position, although this may, of course, give an antinode at another place where some vibration can be tolerated.

The nodes or amplitude measuring points can be chosen arbitrarily, the number and

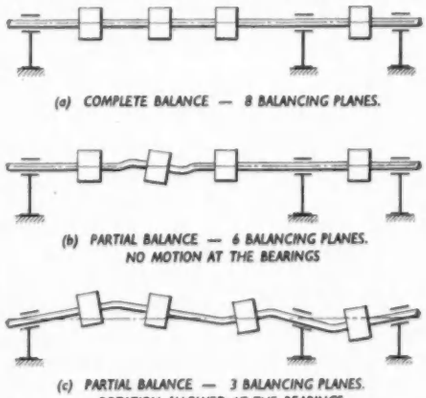
(a) COMPLETE BALANCE — 8 BALANCING PLANES.
(b) PARTIAL BALANCE — 6 BALANCING PLANES. NO MOTION AT THE BEARINGS
(c) PARTIAL BALANCE — 3 BALANCING PLANES. ROTATION ALLOWED AT THE BEARINGS

Fig. 1—Complete or partial balancing of a four-rotor three-bearing machine

position depending upon the degree of balancing required. An example is shown in Fig. 1, of a four rotor machine with three bearings, the connection shafts being flexible. Complete balance as indicated in Fig. 1(*a*)

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Technical Contributors Section (*continued*)

requires eight balancing planes, two per rotor and hence eight measuring points. Six of these points can be on the bearing pedestals measuring the motion in two directions, parallel to the shaft system and at right angles to it. The remaining two positions could be on the shafts. If the requirement is merely that there shall be no motion at the bearing pedestals, some bending of the shaft being permitted, then only six balancing planes and six measuring points are necessary. All the measuring points can then be at the bearings. This condition is illustrated in Fig. 1 (*b*). An even simpler case arises when rotation at the bearings due to bending of the shaft is permissible, as shown in Fig. 1 (*c*). Only three balancing planes and three measuring points are then required, the shaft deflecting freely between the bearings. It is therefore necessary to decide first of all the degree of balancing required and the number of balancing planes and measuring points there will have to be.

A three bearing machine is shown diagrammatically in Fig. 2 with the three bearing pedestals as the measuring points and with three arbitrary balancing planes. The out-of-balance force in any rotor can be resolved into two components in the planes, *a* and *b*, mutually at right angles. The balancing weights can also be placed in the planes *a* and *b* so that their resultant opposes the

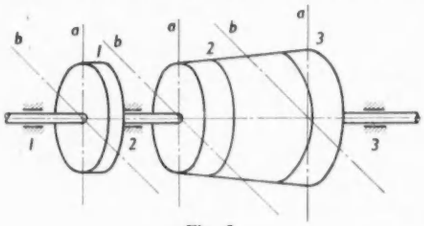

Fig. 2

out-of-balance force. The balancing planes can therefore be chosen arbitrarily, for reasons of accessibility and ease of attachment of weights. Lines denoting the planes *a* and *b* can be marked on accurately during manufacture, and a positive and negative direction relative to the axis of rotation can also be marked on.

The displacement in a particular direction at every measuring point can be regarded as the vector sum of two components due respectively to the out-of-balance force components in all the *a* or *b* planes. The amplitude components at *n* measuring points due to the out-of-balance force components in all the *a* planes are :

$$\left.\begin{aligned} a_1 &= M_1\alpha_{11}+M_2\alpha_{12}+\ldots M_k\alpha_{1k}+\ldots M_n\alpha_{1n}\\ &\ldots\\ a_i &= M_1\alpha_{i1}+M_2\alpha_{i2}+\ldots M_k\alpha_{ik}+\ldots M_n\alpha_{in}\\ &\ldots\\ a_n &= M_1\alpha_{n1}+M_2\alpha_{n2}+\ldots M_k\alpha_{nk}+\ldots M_n\alpha_{nn}\end{aligned}\right\} \quad \ldots\ldots (1)$$

Similarly the amplitude components due to out-of-balance force components in the *b* planes are :

$$\left.\begin{aligned} b_1 &= N_1\alpha_{11}+N_2\alpha_{12}+\ldots N_k\alpha_{1k}+\ldots N_n\alpha_{1n}\\ &\ldots\\ b_i &= N_1\alpha_{i1}+N_2\alpha_{i2}+\ldots N_k\alpha_{ik}+\ldots N_n\alpha_{in}\\ &\ldots\\ b_n &= N_1\alpha_{n1}+N_2\alpha_{n2}+\ldots N_k\alpha_{nk}+\ldots N_n\alpha_{nn}\end{aligned}\right\} \quad \ldots\ldots (2)$$

where M_k and N_k are the out-of-balance forces in the planes *a* and *b* respectively in any balancing plane k, and α_{ik} are the influence coefficients denoting the contribution of an out-of-balance of unit magnitude in the plane k to the amplitude of vibration at measuring point i.

It is clear that to solve these equations the number of measuring points i should equal the number of balancing planes k. Since the planes *a* and *b* are at right angles, the total displacement x_i at each measuring point is the vector sum of the *a* and *b* amplitude components :

$$x_i=(a_i^2+b_i^2)^{\frac{1}{2}}=\{(\sum_{k=1}^{n}M_k\alpha_{ik})^2+\sum_{k=1}^{n}N_k\alpha_{ik})^2\}^{\frac{1}{2}} \quad \ldots\ldots (3)$$

These three equations describe the relation between the measured displacements x_i and the out-of-balance forces M_k and N_k completely. Balancing can be obtained by adding to each rotor a weight at the correct radius to give for the same speed as was used during the balancing test, a total force of $F_k=(M_k^2+N_k^2)^{\frac{1}{2}}$ in a plane making an angle $\tan^{-1}(N_k/M_k)$ with the *a* plane.

Determination of the Influence Coefficients

It is rarely feasible to calculate the influence coefficients accurately for multi-rotor units at the design stage, in view of the unknown stiffnesses of bearing pedestals and foundation. It is better to carry out some experiments on the plant at its final site.

These measurements are best performed with the plant operating each time at the same speed to avoid having to correct the out-of-balance force values for speed differences. This speed should be within the normal operating speed range but not near a whirling speed. For the first test the plant is run in its original state and the displacements x_i are measured at all the measuring points. For the next series of tests, a known mass is attached in turn in the *a* plane on the positive side in each balancing plane to give at the same speed an additional out-of-balance of $\overline{M}_k$. All the displacements are again measured. The new displacement at the i measuring point will therefore be :

$$_{+a}x_i=(_{+a}a_i^2+b_i^2)^{\frac{1}{2}} \quad \ldots (4)$$

where the subscript $+a$ denotes mass addition in the *a* plane and

$$_{+a}a_i=M_1\alpha_{i1}+M_2\alpha_{i2}+\ldots(M_k+\overline{M}_k)\,\alpha_{ik}+\ldots M_n\alpha_{in}=\sum_{k=1}^{n}(M_k\alpha_{ik})+\overline{M}_k\alpha_{ik}$$

which from equation (1) is :

$$=a_i+\overline{M}_k\alpha_{ik} \quad \ldots\ldots (5)$$

The amplitude component in the *b* plane is unaffected by the addition of mass in the *a* plane.

The additional mass is next placed on the negative side of the axis of rotation in the *a* plane, successively in each balancing plane and the displacements at each measuring point will then be :

$$_{-a}x_i=(_{-a}a_i^2+b_i^2)^{\frac{1}{2}} \quad \ldots (6)$$

where

$$_{-a}a_i=M_1\alpha_{i1}+M_2\alpha_{i2}+\ldots(M_k-\overline{M}_k)\alpha_{ik}+\ldots M_n\alpha_{in}=a_i-\overline{M}_k\alpha_{ik} \quad \ldots (7)$$

Squaring and adding equations (4) and (6) and on substituting equations (5) and (7) yields :

$$_{+a}x_i^2+_{-a}x_i^2=2a_i^2+2b_i^2+2\overline{M}_k^2\alpha_{ik}^2$$

and in view of equation (3)

$$_{+a}x_i^2+_{-a}x_i^2=2x_i^2+2\overline{M}_k^2\alpha_{ik}^2$$

The influence coefficients can thus be found from the equation

$$\alpha_{ik}=\frac{1}{\overline{M}_k}\left\{\tfrac{1}{2}(_{+a}x^2{}_i+_{-a}x^2{}_i)-x_i^2\right\}^{\frac{1}{2}} \quad \ldots (8)$$

This equation gives the numerical value of the influence coefficients but not the sign.

It should be appreciated that the influence coefficients could equally well be obtained by placing the additional out-of-balance in the *b* planes. The number of separate tests for a unit with n balancing planes and measuring points is $2n+1$. Two methods of procedure are available for determining the unknown amounts of out-of-balance once the influence coefficients are known.

Zero Method

Complete balancing can always be attained by finding the required amounts and positions of the balance weights for each rotor by trial and error. This is not only laborious but may take a prohibitively long time as some rotors will be less accessible than others. The Zero Method enables the amounts of out-of-balance in each rotor to be determined by tests requiring only a few rotors to be accessible. When all rotors are equally accessible then the rotor whose unbalance has the greatest effect upon the motion at the measuring point under observation can be used. The numerical values of the influence coefficients give a measure of this effect.

The method consists of finding by experiment the amount of out-of-balance that has to be added or subtracted in the *a* plane of an arbitrary balancing plane j to give the minimum amplitude of motion at a measuring point i. This minimum motion measurement indicates then that the amplitude component at the measuring point i due to forces in the *a* direction has been cancelled ; i.e. $a_i=o$.

The amplitude component due to forces in the *b* direction is of course still there. Consider for example the fourth measuring point ($i=4$) and find by experiment the change in out-of-balance in the *a* plane of the second balancing plane ($j=2$) to give the minimum motion at this point. The change in out-of-balance can be denoted by ΔM_{24} (either positive or negative) and from equation (1), the following can be written :

$$a_4=0=M_1\alpha_{41}+(M_2+\Delta M_{24})\alpha_{42}+\ldots M_n\alpha_{4n}.$$

This test is repeated (after removal of ΔM_{24}) for each measuring point and the following set of equations is obtained.

$$\left.\begin{aligned} M_1\alpha_{11}+M_2\alpha_{12}+\ldots M_k\alpha_{1k}+\ldots M_n\alpha_{1n} &= -\Delta M_{j1}\alpha_{1j} \quad \ldots\\ M_1\alpha_{i1}+M_2\alpha_{i2}+\ldots M_k\alpha_{ik}+\ldots M_n\alpha_{in} &= -\Delta M_{ji}\alpha_{ij} \quad \ldots\\ M_1\alpha_{n1}+M_2\alpha_{n2}+\ldots M_k\alpha_{nk}+\ldots M_n\alpha_{nn} &= -\Delta M_{jn}\alpha_{nj}\end{aligned}\right\} \quad \ldots\ldots (9)$$

A similar series of tests has to be carried out with the correcting out-of-balance

(ΔN_{ji}) in the b planes giving the equation :

$$\left.\begin{aligned} N_1\alpha_{11}+N_2\alpha_{12}+\ldots N_k\alpha_{1k}+\ldots N_n\alpha_{1n} &= -\Delta N_{j1}\alpha_{1j} \quad \ldots \\ N_1\alpha_{i1}+N_2\alpha_{i2}+\ldots N_k\alpha_{ik}+\ldots N_n\alpha_{in} &= -\Delta N_{ji}\alpha_{ij} \quad \ldots \\ N_1\alpha_{n1}+N_2\alpha_{n2}+\ldots N_k\alpha_{nk}+\ldots N_n\alpha_{nn} &= -\Delta N_{jn}\alpha_{nj} \end{aligned}\right\} \quad . \; . \; . \; . \; . \; (10)$$

The actual amounts of unbalance in the a and b planes (M_i and N_i) for each balancing plane can be calculated from these two sets of equations and the appropriate corrections made to each plane or rotor in one operation. The suffix j in each set of equations denotes an arbitrary balancing plane which could if necessary be the same throughout and chosen for its accessibility. Some of these tests can clearly form part of the tests required to determine the influence coefficients for such instances where these are not known beforehand or cannot be calculated. This method is useful when the number of balancing planes is small.

The Indirect Method

An alternative and more definite method can be formulated by extending the measurements required for finding the influence coefficients.

The required, but unknown out-of-balance quantities, M_1, $M_2 \ldots M_n$ and N_1, $N_2 \ldots N_n$ in the a and b planes respectively can be calculated from equations (1) and (2) once the influence coefficients have been found and the left-hand sides of the equations are known, i.e. the a_1, $a_2 \ldots a_n$ and b_1, $b_2 \ldots b_n$ amplitudes components. These cannot, however, be measured, but can be derived from the total displacement measurements with the addition of extra mass to one of the balancing planes, chosen again for easy accessibility.

Adding an out-of-balance $\overline{M}_k$ in the positive direction in the a plane of the balancing plane k gives a total measured displacement at any measuring point i, according to equations (4) and (5) :

$$+_a x_i^2=(a_i+\overline{M}_k\alpha_{ik})^2+b_i^2$$

and in view of equation (3)

$$=x_i^2+2a_i\overline{M}_k\alpha_{ik}+\overline{M}_k^2\alpha_{ik}^2$$

and therefore :

$$a_i=\frac{+_a x_i^2-x_i^2-\overline{M}_k^2\alpha_{ik}^2}{2\overline{M}_k\alpha_{ik}} \quad . \; . \; (11)$$

Similarly when the additional out-of-balance $\overline{M}_k$ is placed on the negative direction in the a plane (i.e. the mass is placed on the opposite side of the axis of rotation)

$$-_a x_i^2=x_i^2-2a_i\overline{M}_k\alpha_{ik}+\overline{M}_k^2\alpha_{ik}^2$$

and on combining the last two equations

$$a_i=\frac{+_a x_i^2--_a x_i^2}{4\overline{M}_k\alpha_{ik}} \quad . \; . \; . \; (12)$$

The measurements required for this equation have in fact already been taken for determining the influence coefficients. A sign convention for amplitude components has not yet been introduced. All the a_i components can be taken arbitrarily as positive, whence equation (12) determines the sign of the influence coefficients.

The only additional test required for this method is to add an out-of-balance $\overline{N}_k$ to only one balancing plane on the positive side in the b plane. All other additional masses should, of course, have been removed. The total displacement measured at each measuring point is then :

$$+_b x_i^2=(b_i+\overline{N}_k\alpha_{ik})^2+a_i^2$$

and hence as before

$$b_i=\frac{+_b x_i^2-a_i^2-\overline{N}_k^2\alpha_{ik}^2}{2\overline{N}_k\alpha_{ik}} \quad . \; . \; . \; (13)$$

There is no need to repeat the test with the additional mass on the negative side of the b plane as sufficient measurements will have been taken to solve equation (13), taking into account the signs of the influence coefficients derived from equation (12).

The sequence of tests required is thus :

(1) Amplitude measurements at all points without any additional out-of-balance ; this gives the x_i values.

(2) Additional out-of-balance $\overline{M}_k$ successively to each balancing plane in the a plane and first on one side of the axis of rotation and then on the other side ; each time again measuring the total displacements at all points. This gives the required data for calculating the influence coefficients and also the $+_a x_i$ and $-_a x_i$ values and consequently the a_i amplitude components from equation (12).

(3) Additional out-of-balance $\overline{N}_k$ in one direction in the b plane of one arbitrary balancing plane giving the displacement measurements $+_b x_i$ at each point from which the b_i amplitude components can be calculated. The choice of balancing plane for this test will depend upon accessibility or, if this is immaterial, upon the relative effect on the motion at each measuring point as indicated by the magnitude of the influence coefficients.

Substitution of the values for the a_i and b_i amplitude components and the influence coefficients into equations (1) and (2) gives immediately all the out-of-balance components. This method avoids the "trial" aspect of the Zero Method and involves fewer tests although the computing work may be somewhat heavier. The total number of tests required is $2n+2$. When the influence coefficients are known, however, the number of tests is only three ; the first with the machine unaltered to measure the motion at each measuring point (x_i values) and the second and third with an additional out-of-balance in either the a or b plane of any arbitrary balancing plane to find the $+_a x_i$ and $+_b x_i$ amplitude measurements for use in equations (11) and (13).

Experiments

Some experiments were carried out on a simple apparatus, primarily to determine the effects of errors in the measured amplitudes upon the calculated quantities, and also to serve as an example with numerical values of the application of either method. The apparatus is shown in Fig. 3 and consisted of a $\frac{1}{2}$in diameter shaft supported in self-aligning ball bearings. The shaft carried a number of discs, each drilled along two diameters mutually at right angles to provide a series of holes for attaching out-of-balance weights. The amount of unbalance that could be provided along each diameter had a range of 0·0415oz-in to 3·28oz-in divisible into seventy-nine units, each of magnitude of 0·0415oz-in. The discs could be lined up so that the diameters with the holes corresponded to the a and b planes. The bearings could be mounted in several ways to vary the flexibility of the supports. They could be clamped rigidly to the pedestals or flexible rubber mountings could be inserted as shown in Fig. 3. The disturbing forces were transmitted in the latter case from bearing to bearing mainly by the shaft. The shaft was driven through a flexible coupling by a variable speed motor and belt drive which gave a speed range from 100 to 10,000 r.p.m.

The displacements were measured at the bearing housings with an electromagnetic moving coil transducer clamped to a stand mounted on the bed of the apparatus. The signal from the transducer was integrated to make it proportional to displacement. The maximum trace height on an oscilloscope was measured giving the double amplitude of vibration. The amplifier and oscilloscope screen could be calibrated by feeding in a known voltage signal. The displacement/voltage output characteristic of the transducer was also known and was practically constant for frequencies greater than 25 c/s.

The absolute accuracy of the measuring instruments is of no importance as the object of balancing "on-site" is to reduce intolerable motions to acceptable levels and the measurements required, are all relative. Only casual errors or changes in performance during tests are of importance. The transducer, integrating circuits and amplifier are frequency sensitive to a certain extent, but this is eliminated by doing all tests at the same speed. The maximum error introduced by the transducer depended on the position of the moving coil in the magnet and was 1·2 per cent. The calibrating voltage could be guaranteed to an accuracy of 1·5 per cent. Variations in speed of different tests could be kept to less than 0·5 per cent. By far the largest error arose in reading the trace height on the oscilloscope screen. The transducer, being of the relative displacement type, had to be supported in a clamp. Some vibration of this clamp gave an unsteady trace and errors in reading trace height of up to 5 per cent could have occurred. This can readily be avoided in practice with large machines by bolting a seismic type transducer to the bearing pedestal itself. The maximum error in displacement measurement in these experiments was therefore of the order of 8 per cent and one of the objects was to determine whether such errors made the computing method impracticable.

Experimental Results

The results of a typical arrangement will be given as an example. The system was substantially as shown in Fig. 3 except that there were two discs between bearings 2 and 3 instead of between 1 and 2 ; the discs and bearings being numbered from the free end. The speed of testing was 3400 r.p.m., well removed from any resonance or whirling speed. The horizontal bearing housing displacements were measured first for no additional out-of-balance and then at each bearing housing for additional out-of-balance in each disc in both the a and b planes successively. This gave more measurements than required for a complete balance, but enabled influence coefficients and amplitudes to be calculated repeatedly for comparison.

The measurements are given in Table I. The sets of readings for out-of-balance in the a and b planes enable the influence coefficients to be calculated twice (equation (8)). The values are given in Table II. The signs have been determined from the readings for the a plane according to equation (11) by taking the displacement a_i as always positive. This is quite arbitrary and the readings for the b plane could have been taken just as well. The difference between these two sets of coefficients is not greater than 4 per cent except for some of the smaller values which are not very important in any case.

The measurements with the additional out-of-balance in either the a or b planes allow the amplitude components a_i and b_i to be calculated four times for each measuring point according to equation (12), without having to use the measured total displacement x_i, except in so far as these measurements have been used to obtain the

Technical Contributors Section *(continued)*

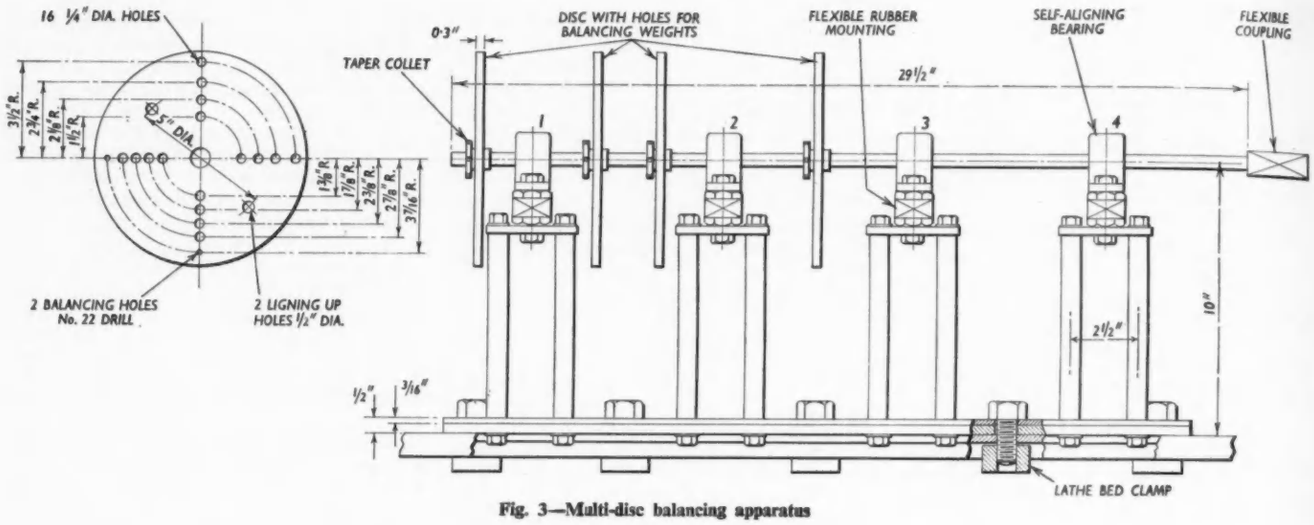

Fig. 3—Multi-disc balancing apparatus

TABLE I—*Amplitude Measurements in Microns at the Bearings.*

		Balancing planes							
		a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
Unbalance units	0	+15 −15	+15 −15	+34 −34	+34 −34	+34 −34	+34 −34	+34 −34	+34 −34
x_1	120	259 51	216 58	232 49·1	195 139	94 148	112·5 135	85·5 57·3	111 140
Unbalance	0	+23 −23	+23 −23	+34 −34	+34 −34	+23 −23	+23 −23	+23 −23	+23 −23
x_2	67·5	30 115	92·5 72	166 42	112 136	227 94	161 182	236 110	174 200
Unbalance	0	+34 −34	+34 −34	+34 −34	+34 −34	+23 −23	+23 −23	+23 −23	+23 −23
x_3	57·7	23 24·5	+84·5 102	125·6 20	102·6 84·5	139 32·8	113·5 95·6	157·5 49	127 111
Unbalance	0	+19 −19	+19 −19	+23 −23	+23 −23	+23 −23	+23 −23	+34 −34	+34 −34
x_4	127	277 98	260 141	65·5 224	118 206	80·6 252	127·2 228	76·1 198·5	110 183·1

TABLE V—*Amplitudes by the Zero Method*

	Amplitudes, microns				
i	a_i	b_i	x_i	Measured x_i	Percentage difference
1	109·8	39·1	116·4	120	−3·0
2	66·0	−13·7	67·3	67·5	−0·3
3	55·0	13·6	56·9	57·7	−1·4
4	104·0	70·0	125·5	127	−1·2

influence coefficients. The total displacement for the system without mass addition can therefore be calculated, using the equation

$$x_i=(a_i^2+b_i^2)^{\frac{1}{2}} \quad . \quad . \quad . \quad (14)$$

and compared with the actual measurements. This gives a clearer picture of the scope of the Indirect Method than calculating the original out-of-balance which was unknown in any case. This comparison is shown in Table III. The percentage differences between calculated and measured amplitudes were, in fact, less than the maximum possible experimental errors, even though some of the differences between successive a_i and b_i values were rather large.

TABLE II—*Influence Coefficients*

The first value was derived from out-of-balance in the *a* plane and the second from the *b* plane

i \ k	1	2	3	4
1 ...	+9·53 +9·77	+3·44 +3·50	−0·67 −0·70	−1·18 −1·14
2 ...	−2·17 −2·09	+2·96 +3·08	+6·95 +6·87	+7·46 +7·6
3 ...	−2·01 −2·18	+2·03 +2·17	+3·63 +3·78	+4·40 +4·54
4 ...	+8·64 +8·73	−4·59 −4·78	−5·99 −5·83	−2·40 −2·37

TABLE III—*Calculated and Measured Amplitudes*

	Amplitude-microns Calculated					Percentage difference
	1	2	3	4	Average measured	
a_1	112·7	110·0	107·2	108·9		
b_1	37·2	39·5	44·0	45·8		
x_1	119	117	116	118	117·5 120	−2·1
a_2	61·6	64·1	66·4	65·9		
b_2	− 17·4	−14·5	−11·4	−13·9		
x_2	64	65·8	67·3	65·5	65·6 67·5	−2·8
a_3	54·8	55·8	55·0	55·3		
b_3	11·6	11·5	10·6	9·1		
x_3	56·0	56·9	56·0	55·9	56·2 57·7	−2·6
a_4	102	108·7	103·7	104·9		
b_4	71·4	64·5	66·8	65·4		
x_4	124·5	126·1	123·5	123·3	124·4 127	−2·0

The system was also balanced according to the procedure of the Zero Method. The displacements at each bearing housing were made a minimum by successively placing balancing weights in the *a* and *b* planes of some of the discs. Only those discs were used which gave the greatest effect upon the motion of the measuring point in question, i.e. the highest influence coefficient. Additional out-of-balance on disc number 2 had little effect and was not used. This was done only to obtain more accurate measurements for comparison with the previous results. Application of the Zero Method for balancing each disc is quite straightforward and requires only patience. The amounts of correcting balance are given in Table IV to the nearest half-unit of unbalance.

These results can be compared with those obtained by the Indirect Method by calculating the a_i and b_i amplitudes. Combining equations (1) with (9) and (2) with (10) gives

$$a_i=-\Delta M_{ji}\alpha_{ij} \text{ and } b_i=-\Delta N_{il}\alpha_{ij}$$

and the total displacement can then be calculated from equation (13). The influence coefficient values were taken from Table II. The calculated amplitudes are given in Table V and the values for a_i and b_i should be compared with those of Table III. Comparison of the calculated total displacements with the measured values again shows the former to be slightly smaller.

TABLE IV—*Additional Balance (in Units) Required to give Minimum Total Displacements According to the Zero Method*

Bearing numbers	1	2	3	4
ΔM_n	ΔM_1= −11·5	ΔM_2= −9·5	ΔM_3= −12·5	ΔM_4= +17·5
ΔN_n	ΔN_1= −4	ΔN_2= +2	ΔN_3= −3	ΔN_4= +12

It is noted, however, that all the calculated values are less than the measured. This may have been due to non-linearity in the stiffness of the rubber mountings.

Conclusions

An "on-site" balancing technique for multi-bearing systems has been developed requiring only simple total displacement measurements at a number of preselected points and without regard to any phase relationships. Two different approaches are available; the Zero Method being primarily experimental, whereas the Indirect Method requires a definite number of separate test runs to be made, the total number being $2n+2$ where n is the number of balancing planes. The experiments showed that consistent results could be obtained with either method even with rather inaccurate measuring techniques.

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Development and Production of Improved Heat Insulation Material

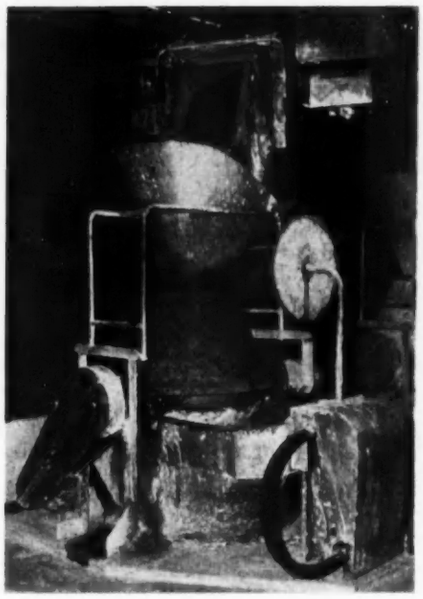
To strengthen its competitive position the Chemical and Insulating Company, Ltd., has been engaged on a programme of research to improve product quality and also production methods. This has resulted in modification to the process, to give chemical bonding and improved physical properties, and the development of automatic controls and precision moulding to provide economic production.

THE Chemical and Insulating Company, Ltd., presently the chief manufacturing company of the Darlington Chemicals, Ltd., group of companies, was established at Darlington in 1929, close to the source of its raw material. This is dolomite limestone, which is present in large quantities in County Durham, and from which magnesium compounds are extracted. Since then the company has been producing 85 per cent magnesia insulation and a wide range of associated insulants, finishing materials and magnesia chemicals. Magnesium carbonate, oxide and hydroxide, in industrial and pharmaceutical grades, are produced, and it is the carbonate which is used as the basis for the insulation material. Light basic magnesium carbonate mixed with 15 per cent of long fibred asbestos and known as 85 per cent magnesia has long been a standard insulation material which has been filter moulded into preformed pipe sections and slabs.

To improve both the product and its method of production has been the active concern of the company for some years, and as a result of an intensive research programme a modified form of magnesium carbonate has been produced and a new production technique evolved. The new material is known as 85 per cent super-magnesia. The main characteristic of the new product is that, in addition to the binding effect of the asbestos fibre reinforcement, it is chemically bonded together, in that the crystals grow round the asbestos fibres to form a strong network. This growth gives the product high mechanical strength, high resistance to vibration and good retention of shape after wetting. Precision moulding for the manufacture of sections has been developed so that close dimensional accuracy is attained, to ensure a close fit, and the product has a smooth surface. The following are the main properties of 85 per cent super-magnesia: Density, 11 lb to 12 lb per cubic foot ; Modulus of rupture, in excess of 65 lb per square inch ; Crushing strength (5 per cent deformation), in excess of 75 lb per square inch ; Linear shrinkage, less than 1·5 per cent after twenty-four hours soaking at 650 deg. Fah.; Maximum service temperature 650 deg. Fah.; Thermal conductivity ranges from 0·36 to 0·51 B.Th.U./inch/square foot/hour/deg. Fah. over a mean temperature range of 150 deg. to 350 deg. Fah.

The above data compare with the following which relate to 85 per cent Magnesia. Density, 12 lb to 13 lb per cubic foot ; Modulus of rupture, in excess of 55 lb per square inch; Crushing strength (5 per cent deformation), about 40 lb per square inch ; Linear shrinkage, less than 2 per cent ; Maximum service temperature, 650 deg. Fah.; Thermal Conductivity 0·42 to 0·52 B.Th.U./inch/square foot/hour/deg. Fah. over a mean temperature range of 150 deg. to 350 deg. Fah.

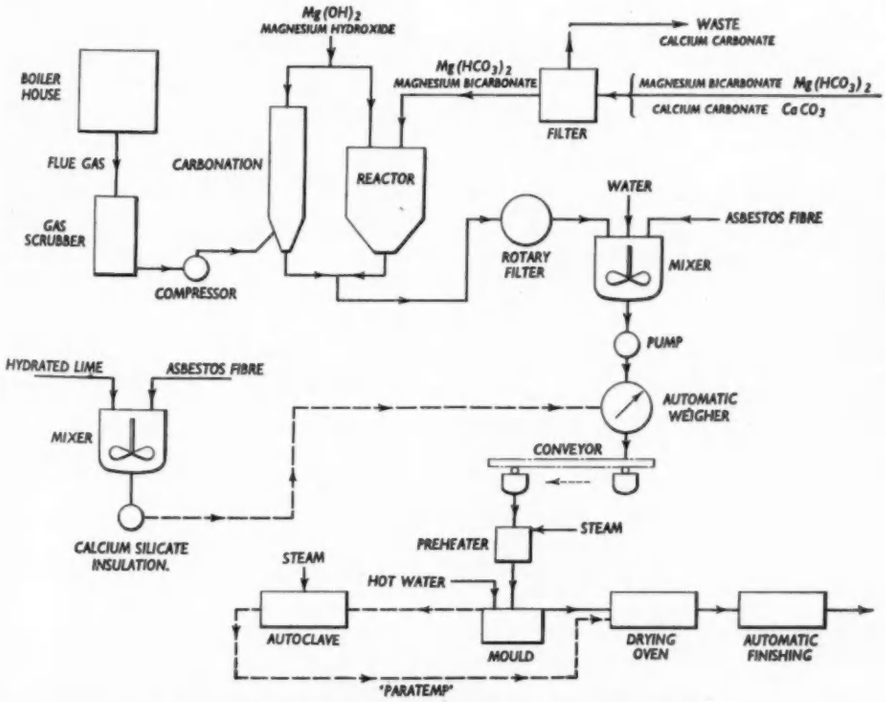
Also produced by the same precision moulding equipment is " Paratemp," which is a calcium silicate insulation material specially developed for the petroleum and chemical industries. It can be applied direct up to a temperature of 1400 deg. Fah. and retains a high proportion of its compressive and flexural strength after prolonged use at maximum temperature. The main properties of the material are : Density, 12 lb per cubic foot ; Modulus of rupture, 60 lb per square inch ; Compressive strength (5 per cent deformation), 70 lb per square inch ; Linear shrinkage, 1 to 2 per cent after soaking for twenty-four hours at 1200 deg. Fah. ; Limiting temperature, 1400 deg. Fah.; Thermal conductivity 0·40 to 0·72 B.Th.U./inch/square foot/hour/deg. Fah. over a mean temperature range from 200 deg. to 900 deg. Fah.



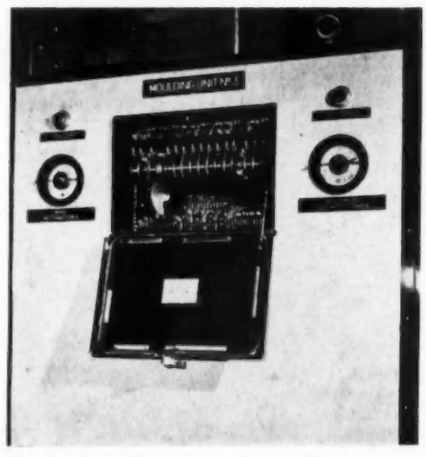
Preheater shown being loaded from a monorail hopper

Production Process

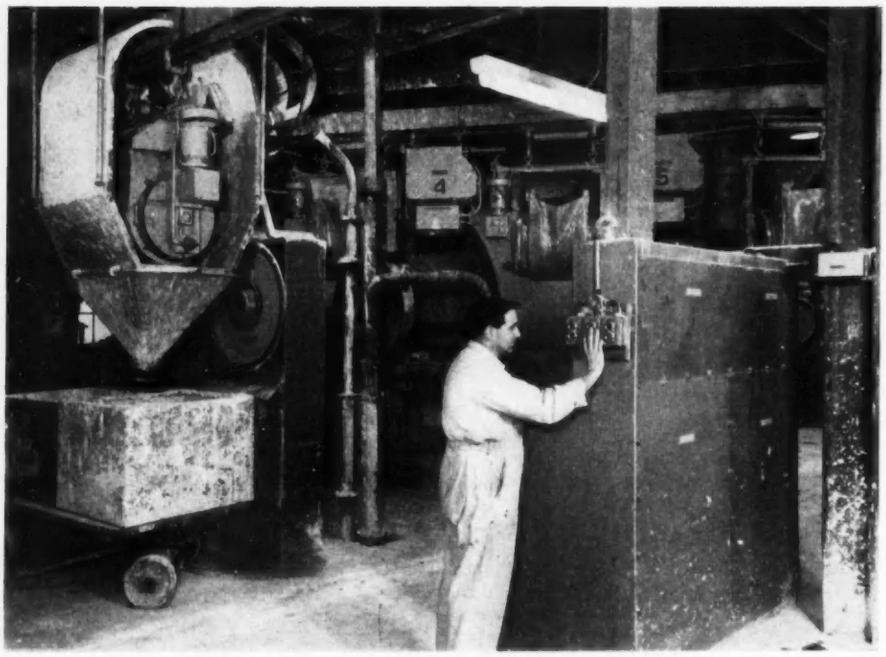
In the production of light basic magnesium carbonate, dolomite coke undergoes a calcination process in a kiln, and the magnesium and calcium oxides produced are crushed and passed through a hydration stage to produce hydroxides. These are pumped through a two-stage grit separator and the mixed hydroxide slurry is pumped to a dilution unit, where water is added, and then pumped to the top of the primary stage of the



Flow diagram for 85 per cent super-magnesia and for " Paratemp "



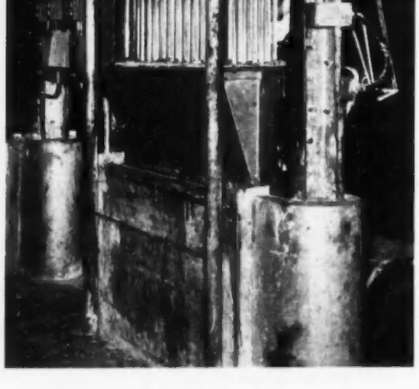
Mould station operation sequence and timing control unit



Automatic weighing machine and filling station and conveyor system

two-stage carbonation process. Kiln gas, which has been treated in a two-stage scrubber, is compressed and admitted at the base of the primary stage column to provide a counter current flow. From the primary column the slurry passes by gravity flow to the secondary stage column, at the base of which compressed carbon dioxide is admitted. The product, consisting of magnesium bicarbonate in solution and calcium carbonate, is filtered to remove the latter. Up to this point the process is the same for both the 85 per cent super-magnesia and the 85 per cent magnesia.

For the production of the latter and the pharmaceutical products the magnesium bicarbonate is passed to a kettle to which steam is admitted. Steam and carbon dioxide are given off; the former is condensed and the latter is forwarded to a gas holder and then used as feed to the secondary stage of the carbonation unit. From the kettle the 2 per cent solution of light basic magnesium carbonate passes through a Dorr Oliver thickener to storage as a 5 to 7 per cent solution. For the manufacture of 85 per cent magnesia, this slurry is mixed with asbestos fibre and is filter moulded under an air pressure of about 45 lb per square inch. The moulded product, which is 10 per cent oversize to allow for shrinkage, and for which supports have to be provided, passes through drying stores and on to the finishing section. For the production of chemicals the solution from the storage tanks passes through a rotary filter and is then dried to form light basic magnesium carbonate which is calcined at about 1000 deg. Cent. to give light magnesium oxide and then hydrated to produce magnesium hydroxide.



Mould with filling assembly in position

As already mentioned, the process for both products is the same up to the final filtration stage where the calcium carbonate is removed as waste. For super-magnesia, as can be seen in our flow diagram, the magnesium bicarbonate solution is reacted with magnesium hydroxide to produce a 10 per cent suspension containing magnesium carbonate tri-hydrate crystals, which are of needle shape and measure, on average, 30 microns by 7 microns. Similar crystals are formed by carbonating magnesium hydroxide using scrubbed boiler flue gas, which is compressed in Nash Hytor rotary compressors and enters the base of the carbonation column. Water is removed from the suspension in a rotary filter and the solids passed to a mixing tank where water and special quality asbestos fibre are added and the whole mixed into a paste of controlled density. From the tank, the paste is pumped, via an automatic weigher, into a travelling hopper. An operator selects the weight of material required to feed the hopper and the weighing machine automatically takes into account the tare weight of the hopper, and so adjusts for any build-up of material within the hopper. By means of a control panel the hopper, via a British Mono Rail system, delivers the material to a selected preheater unit and a signal informs the mould operator that the system is ready for operation. The hopper rotates through 360 deg. to return to the upright, then the motorised unit returns to the filling station where interconnecting solenoid operated valves once again start the flow of the material. Our illustration shows part of the conveyor system and one of the travelling hoppers at the automatic weigher and filling station. Each preheater, illustrated herewith together with operation sequence and timing control unit, consists of a bowl, shaped in the form of a concrete mixer, and on a signal from the mould operator, on the floor below, the bowl tilts and starts revolving while at the same time the mouth of the bowl is closed by a lid fitted with a pipe through which steam is now admitted to the bowl to heat the contents. The operator gives the signal to initiate the system when the previous set of sections have been ejected from the mould. While the mould is being cleared the temperature of the suspension in the bowl is being raised to about 120 deg. Fah., the time required being approximately five minutes. The mould filling assembly, which is connected to the outlet hopper of the preheater by a chute, descends to the mould surface ready to receive the heated suspension. Each mould consists of a welded box provided with hot water heating connections and fitted with moulds which are accurately machined and equipped with pistons. These pistons commence to descend after the mould hopper has been filled with the heated suspension which, aided by a number the vibratory fingers, flows into the mould cavities. The fingers are slowly retracted and the filling assembly is raised. In our illustrations can be seen a filling assembly and vibratory fingers with a mould below, and also the filling assembly raised and the moulds being automatically ejected. The residence time of the sections in the mould depends upon the size of the section, and during this period the hot water heating promotes a chemical reaction in the suspension, which is converted into a solid mass. The sections are now ejected from the mould by the pistons and are lifted on to bogies

Filling assembly in raised position with sections being automatically ejected

ready to be transported to the drying ovens, through which they pass on a semi-continuous basis. When dry the moulded sections pass to an automatic finishing line. Pipe sections are forwarded to a vee flight conveyor which feeds the pipes to twin band saws, for cutting to length, and another conveyor passes them to a band saw which cuts them in half lengthwise. Off cuts, which are much smaller than those resulting from the finishing operations in the sections manufactured by the filter moulding process, are crushed and bagged. This fibrous powder is used as a plastic insulant and, mixed with water, 1 ton has a covering capacity of 2200 square feet by 1in thick.

"Paratemp," the calcium silicate insulation, is manufactured from hydrated lime,

silicious constituents and asbestos fibre. These materials are mixed with water and agitated under controlled conditions to produce a uniform suspension to which colouring matter is added to distinguish the material from 85 per cent super-magnesia. After mixing, the suspension is processed in the same manner as the 85 per cent super-magnesia except that both the preheating and mould temperatures are higher and further treatment is required, to complete the formation of the correct calcium silicate crystals, before the moulded section is forwarded for drying and finishing. In this final process the moulded pieces are loaded into an autoclave to which steam at 120 lb per square inch is admitted. " Paratemp " is produced in the same sizes as 85 per cent super-magnesia that is in preformed sections for pipes from ¼in to 8½in outside diameter and flat slabs in sizes up to 36in by 12in and in thicknesses of 1in, 1½in and 2in.

Electrical Plant in Petroleum Installations

In a paper presented to the Association of Supervising Electrical Engineers, London, on February 21, Mr. W. J. F. Cocks dealt with the operation of electrical plant in hazardous areas. The following extracts from the paper are concerned with modern installations in petroleum depots and trends such as the use of a computer to give instructions for the controlled loading of vehicles in a petroleum depot. In the earlier part of the paper (not reproduced here) the author discussed codes of practice for electrical plant in petroleum installations with particular reference to flameproof and intrinsically safe equipments.

The Modern Petroleum Installation

IT is of interest to examine the forms of electrical apparatus which operate in the most modern petroleum installation and from which it is possible to forecast future trends in design which may have far reaching effects on other industries apart from the distribution of petroleum.

There is a possibility that future large petroleum depots within this country may be pipeline fed from refineries and this will require extensive remote control of valves to tankage together with instrumentation as adopted in refineries and large chemical plant. Different grades of petroleum product may be transported over a single pipeline and although it is not essential in all cases these are sometimes separated one from another by synthetic " rubber " spheres or by a line pig inserted at the transmitting end of the pipeline at the time when changing products.

The operational staff within the receiving installation are advised by telephone or radio communication that pumping of a certain product has commenced and with a knowledge of pipeline capacity and pumping characteristics, it is possible to estimate the approximate time of its arrival at the installation. The specific gravity of the product is constantly monitored by an auto-gravitometer connected to the pipeline and this information together with pressure conditions (and temperature in the case of black oils) are transmitted from the hazardous area to the main control console by intrinsically safe circuits. The gravitometer is fitted with adjustable contacts which can be set to a certain value and when the change in specific gravity occurs, an alarm is sounded to draw operators' attention to the line conditions. Detectors are fixed to the pipelines to indicate the arrival of the separating pig or sphere in the pipeline.

On receipt of the product at the depot, flameproof motorised valves or actuators on the main pipeline manifold may be operated remotely from the main console and the new product routed to the particular storage tank. The flameproof motorised valves are arranged to operate in groups so that while certain valves are opening others are closing; suitable interlocks are of course employed to ensure that certain valves cannot be operated when others are in the open position. All manually operated manifold valves which can be set to the required condition prior to the arrival of product over the incoming pipeline are fitted with flameproof switches to give remote indication whether the valve is open or closed. The indicating lamps are incorporated in a mimic diagram.

The main control console can include the receivers for the level and temperature remote indication equipment and these items can be fitted into the pipeline mimic diagram for the installation. This arrangement provides full information on stock position and control over the incoming product.

Pumping continues day and night until the required quantity of products has been delivered and in view of the fact that a limited number of personnel must always be present for chemical sampling apart from control work, advantage is taken to install any other alarm/indication circuits on the console so that any abnormal conditions can be attended to promptly. One of these, for instance, concerns the prevention of any product passing into the main drainage. Drainage from petroleum storage areas is taken to an interceptor and in the inlet chamber of this a probe is fitted attached to a float on the liquid which is energised from an intrinsically safe circuit. In normal operation, the circuit is conducting through the water, but the introduction of any oil on the surface of the water introduces a high resistance and the interruption of the circuit causes a relay to fall out and make a contact pair which energises a solenoid on a spring loaded valve which closes and prevents liquid leaving the interceptor until action is taken to remove the product from the water surface. The main control console can of course include any remotely operated valves associated with the loading of vehicles and in addition any form of apparatus for controlled loading of vehicles.

Some time ago an investigation was initiated to determine whether it would be feasible to produce equipment for use in a depot which could create error free data in a form suitable for future business machines, bearing in mind that 85 per cent of customers order by telephone and each year the depots make out more than 3,000,000 sales tickets which lead to over 5,000,000 punched cards and 1,250,000 invoices.

In July, 1960, a Direct Order Recording and Invoicing System known, for short, as " Doris " was installed at Royston Installation and this equipment is mentioned because certain additional apparatus could be installed at this particular depot which might provide automatic loading of vehicles in a hazardous area from data provided either by " Doris " or other apparatus of that type. The " Doris " equipment at Royston could handle 3000 customers' orders and the customers' names are arranged in alphabetical order on push buttons on a main input console in the form of a seven sided " cubicle " as shown in the accompanying illustration.

When a customer telephones, the sales clerk depresses the push button bearing his name together with the order detail push buttons as required which are located on a small panel immediately in front of the sales clerk. All order details are perforated on paper tape and as this takes about four seconds and an average telephone call takes fifteen seconds, there can be no delay in handling orders. The tape is automatically read and production of the issue document commences. Full information about the customer and product is stored on reels of seven-channel strengthened paper tape ; five

" Doris " (Direct Order Recording and Invoicing System) showing customers' names and push buttons arranged on a main input console in the form of a seven-sided cubicle. It is installed at the Royston petroleum depot

channels are used for normal letters and numerals as on ordinary teleprinter tape ; the sixth is used for machine control codes and the seventh for customer identifications, which permits high-speed counting by photo-electric cell until the required information is reached, the read-out is then at teleprinter speed. The description and price of the product are printed on the sales ticket, the value of the total order worked out and the customer's invoice prepared. The equipment prepares a permanent record of orders for all subsequent accountancy and statistic processes required together with a summary of the day's transactions.

It is interesting to note that the equipment is almost entirely electromechanical rather than electronic since speed of processing was found to be adequate by this method and maintenance and staffing problems greatly simplified.

It will be observed that if suitable equipment can be designed it will be possible to introduce a form of " automation " within the depot which will carry out automatically all processes between the receipt of a customer's order by telephone and the loading of product into the road vehicle tanks, although this arrangement may not be economically justified at the present time.

However, a number of oil companies have the problem of automation under investigation and certain types of apparatus have been introduced for long term testing and observation. It will be appreciated that where a storage installation is handling considerable throughputs of a very limited number of products and a large number of road vehicles are employed it is possible to introduce a system whereby additional pumps are automatically brought into operation as required by means of flow sensing devices, or motor control gear which includes apparatus for measuring the load current taken by motors in operation ; depending upon a rise or fall in this current, motor driven pumps are switched on or cut out.

Automatic loading controlled from a console in the main office would require equipment which can take all necessary instructions from a punched tape or punched cards, possibly prepared by business machines of the type already described in this paper, and ensure that these instructions are obeyed without error. The associated apparatus for loading must be suitable for operating in a hazardous location.

The equipment would require a number of either flameproof or intrinsically safe guard circuits to ensure that :

1. The correct product is loaded.
2. The correct product is loaded into the correct tank section of the vehicle.
3. Where the vehicle has a number of tank compartments of either different capacity or compartments which were partially filled, it must not be possible to overfill the tank.
4. The vehicle is earthed.
5. The filling arm is fully lowered into the tank and does not permit splash fillng which could be dangerous from the electrostatic aspect.
6. The correct quantity of product is loaded.

The equipment would require remote counting apparatus which would be connected to the meter and the information conveyed to the control console possibly by intrinsically safe circuits. To avoid hydraulic shock on the product pipeline system, it would be necessary to employ one or more flameproof solenoid operated valves which progressively shut off product flow prior to the correct quantity being delivered to the vehicle.

It will be noted that to meet all requirements for safe and correct operation it may be necessary to incorporate switches on the vehicle filling holes which are operated by the insertion of the filling arms and furthermore, the vehicle circuits may have to contain resistors of different values for compartment identification. All guard circuits from the vehicle and filling gantry could be run in multicore telephone type cable to the console and possibly be connected to a bridge circuit in which a null detector would only close a switch if all safety conditions are met.

Future Developments

The continued use of flameproof equipment in the open is considered necessary, and it is pleasing to note that many authorities and industry are taking such action to ensure that electrical apparatus used in hazardous areas will have suitable flameproof-weatherproof enclosures. There will be a great increase in the use of intrinsically safe equipment owing to the ease with which it may be applied to instrumentation and electronic apparatus used in hazardous areas for the completely automatic control of process plant in the oil and chemical industries. If it can be shown to be economical, large depots and installations may be pipeline fed and this will require control equipment of the type mentioned above with all improvements found necessary from operational experience.

The introduction of business machines into the petroleum depot may have far reaching developments on operations as undertaken to-day, and future equipment operating over land lines or microwave links in conjunction with a central computer which can give instructions for the controlled loading of vehicles may show considerable saving in operating costs.

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Pedestrian Crossings

THE Traffic Engineering Study Group of the Institution of Civil Engineers met on February 16 to discuss pedestrian crossings. A paper on the subject was presented jointly by L. A. Laffan, B.Sc.(Eng.), Head of the Traffic Group, Chief Engineer's Department, London County Council, and R. A. Wright, M.A., A.M.Inst.T., General Assistant to the Traffic Manager, British Railways. Mr. H. J. B. Harding was in the Chair.

Although subways formed the title subject of the paper, the discussion ranged over all forms of road crossing provided for the pedestrian—and many of the speakers took the opportunity of revealing their attitude towards the pedestrian. On the whole the Group seemed in favour of inducing, rather than compelling, the pedestrian to conform ; but certain extreme views were expressed. On-the-spot fines, and a policeman to tap you on the shoulder the moment you step off the kerb at the wrong place, were one speaker's solution. He received some support from a self-confessed jay walker who had felt no grievance over being both hospitalised and penalised in Liége ; and the meeting was assured that in Vancouver it is no hardship to cross at the street corners only. On the other hand there were warnings against " bullyragging " the pedestrian, who must be allowed his rights, and is anyway, as often as not, only " a motorist who has succeeded in parking his car " ; and someone remarked that it is often a good thing to stop the traffic to let side traffic filter in. However these were asides compared with the main problem to which the Group addressed itself : the problem of providing crossings attractive enough to deter the pedestrian from crossing the road elsewhere.

Many of the speakers had carried out research into the problem. According to one the ruling factor is the time taken, rather than the energy expended ; one of his graphs showed that when it takes one-and-a-half times longer to use a subway or overbridge than to wait and walk across the road without risk, the subway or overbridge goes unpatronised. But, it was pointed out by another speaker, as the years go by people have to wait longer before they can walk across in safety ; he had noticed in his area that, even at zebra crossings, people were becoming more hesitant in the face of the faster modern motor vehicles ; subways and overbridges would gain in importance.

The question of whether to construct an overbridge or a subway produced, on balance, the answer that in new development, or in urban redevelopment, there is often great scope for incorporating the pleasanter and cheaper overbridge without incurring the excessive climbing and descending that militate against its usefulness when it is erected over an existing road. One engineer described how his overbridges " stand there year after year unused " because of their height, dictated by the standard 16½ft clearance. Subways have to drop only about 12ft, though sometimes as much as 15ft is necessary in order to accommodate city utilities above them.

Data contributed by speakers who had conducted traffic surveys in subways included the following points : the mean free-flow speed is 3·6 m.p.h. on the level, 1·8 m.p.h. up steps and 2·2 m.p.h. down steps ; the corresponding comfortable capacities, in persons per foot width per minute, are 27, 19 and 21 for widths not less than 4ft, and these figures apply to both one-way and two-way traffic ; they also allow for a standard of marching inferior to that of soldiers in threes for whom the capacity figure would be 37. Overcrowding, up to the limit of 2 square feet per person, slows the pace down to about 1 m.p.h. without materially affecting the throughput so long as the exit remains clear. Gradients of up to 1 in 10 are acceptable ; there were divided opinions on the acceptability of intermittent flights of steps to save length ; perambulators make steps and staircases a last resort.

Escalators (moving staircases) were discussed as a means of popularising subways ; the type installed at London Underground stations have an inclination of 30 deg., tread width 3½ft, speed 140ft per minute, capacity about 130 persons a minute. It was pointed out that in the open air, at entrances to a subway, they would be more costly in maintenance ; a shelter over the entrance would create blind spots for the vehicular traffic and probably involve the acquisition of additional property. At least one speaker felt that there should be less compunction

(and delay) over acquiring property; he visualised the taking-over of the ground floor and basement of a corner shop, which could then be equipped with automatic lifts serving a subway. In any event the meeting agreed on the need to design subways for popularity; at the western end of Westminster Bridge the percentages of pedestrians using the subways to cross Bridge Street and the Victoria Embankment are only seven and twenty-five respectively. Two novel designs that have already been used were mentioned. In one of them, to be found in Birmingham, the entire pavement (sidewalk) slopes down into the subway system so that a pedestrian approaching this crossroads finds himself in the subway willy-nilly, even if he only intends turning right; it was remarked that this design lends itself to the inclusion of shops in the subway, which are always a popular feature and help to pay for the construction. The other design mentioned was the Kent one used for the A.20 crossing at Preston Hall, near Maidstone; spiral entrances, with an inner ring of steps, and an outer ring in the form of a ramp, give the pedestrian a wide choice of gradient.

The costs of subway construction—which are considerable—came under discussion frequently, but unfortunately the figures given by the different speakers did not tally and no reliable yardstick emerged.

Obituary

SIR ARTHUR CROFT

SIR ARTHUR CROFT, whose death, we regret to announce, took place on February 12, was a very well-known figure in the field of power transmission, and had seen his company, Crofts (Engineers), Ltd., Bradford, 3, grow from modest beginnings in 1887 to become one of the world's largest manufacturers of power transmission equipment.

Arthur Croft was born on March 14, 1886, and was educated at Hanson's School and Bradford Technical College. He joined the family firm of Crofts as an apprentice just sixteen years after it had been founded by his father, the late Frederick Lister Croft, with a total personnel of seven. When the business became a private limited company in 1907 Croft was appointed a director, and on his father's death in 1920 he became joint chairman. He became governing director in 1936, and when the public company was incorporated in 1948 he became chairman and managing director. Sir Arthur was knighted in 1953, and retired from the company in the same year, shortly after completing fifty years of service.

Sir Arthur was particularly interested in the welfare of the employees of Crofts, and was responsible for the provision of sports fields and a recreation hall, and for the introduction of superannuation, insurance and bonus schemes. He is survived by Lady Croft and by his son and daughter; the former, Mr. John Croft, succeeded his father as managing director of the firm in 1953.

SIR CHARLES REID

WE regret to have to record the death, on February 19, of Sir Charles Reid, who was an outstanding mining engineer and made his way, by his own force of character and ability, from humble beginnings to the top of his profession. Charles Carlow Reid was born on January 27, 1879. On leaving school at Leven, Fifeshire, he became an apprentice clerk, but when his apprenticeship was over, he went down the pit and so began his long career in mining. Promotion was rapid, and he became, in succession, assistant to the manager at Aitken Colliery, manager of Donibristle Colliery, and agent to a group of collieries owned by the Fife Coal Company. By 1923 he was general manager of the whole of the company's undertakings, and by 1931 a director and general manager. In 1942 Reid was seconded to Government service, and became, first, Regional Production Director for Scotland under the Ministry of Fuel and Power, and secondly, a year later, Director of Coal Production for Great Britain.

In October, 1944, Reid was appointed chairman of a committee charged with the investigation of the technical aspects of the British coal industry, and in April of the following year, the committee's report—widely known as the "Reid Report"—was published. It was a forthright document which aroused considerable interest at the time and was interpreted by some as a demand from the highest technical authorities for nationalisation of the mines.

Sir Charles Reid—he was knighted in 1945—was appointed a member of the National Coal Board at its inception, but resigned in May, 1948, as he did not agree with the organisation it had set up. His only son, Mr. William Reid, is now chairman of the Durham Division, National Coal Board.

SIR OLIVER LYLE

SIR OLIVER LYLE, who died in London on February 21, was vice-chairman of Tate and Lyle, Ltd., and an authority on the technology of sugar refining. To engineers generally, however, there is no doubt that he will best be remembered as an expert on the efficient use of fuel, and in particular on the problems of economic steam utilisation, a subject he had made especially his own.

Oliver Lyle was born on December 22, 1890, and was educated at Uppingham and London University. He joined Abraham Lyle and Sons in 1912 and was appointed to the board of the company in 1919. When Abraham Lyle and Henry Tate and Sons amalgamated in 1921, Oliver Lyle became a managing director of Tate and Lyle, Ltd. He was appointed a vice-chairman in 1958.

In the 1914–18 war he served as a Captain in the Highland Light Infantry, was wounded at Loos in 1915, and was twice mentioned in dispatches. From 1916 to 1918 Lyle was engaged in the Inventions Department, Ministry of Munitions, and for his work there was awarded an O.B.E. in 1919. He was a Fellow of the Institute of Fuel, and from 1942 to 1953 was a member of the Fuel Efficiency Committee; for his services to fuel technology he was knighted in 1954.

Sir Oliver Lyle was the author of *Technology for Sugar Refinery Workers*, 1941, *The Efficient Use of Fuel*, 1947 (a Government publication which was re-issued several times, the sixth impression having been published in 1958) and *The Plaistow Story*, 1960. Sir Oliver had that rather rare combination of executive skill, theoretical knowledge and manual craftsmanship, and is remembered by his colleagues and friends as a man who had great patience as an experimenter and who brought his passion for perfection to bear on all the problems he tackled.

MAJOR J. B. L. THOMPSON

WE regret to record the death of Major J. B. L. Thompson, which occurred on January 23. Major Thompson was born in Carlisle in 1890, and after attending Carlisle Grammar School was articled in 1907 to the late Henry C. Marks, City Engineer and Water Engineer of Carlisle. In that city Major Thompson rose to the position of Chief Engineering Assistant, but in 1915 he left on receiving a commission as second lieutenant in the Royal Engineers. Later he was appointed second in command of the 313 Road Construction Company, R.E., and was subsequently awarded the Military Cross. Promotion followed and Major Thompson was appointed Officer Commanding, 339 Road Construction Company, R.E.

After his war service Major Thompson became, in 1922, Deputy Borough Engineer and Water Engineer of Hastings, and two years later he accepted the position of Borough Surveyor, Engineer and Water Engineer of Swindon, which post he held for nearly twenty-three years. Major Thompson became a Student of the Institution of Municipal Engineers in 1907, and progressed through Associate Membership and Membership to become President of the Institution in 1947.

H. C. WOOD

WE regret to have to record the death, on February 6, 1961, of Mr. H. C. Wood. Harold Carrington Wood was born on February 28, 1882, and was educated at Hereford County College, Reading School and University College, London. He joined the Airdrie Iron Company as an apprentice in 1901, and during his apprenticeship studied mining engineering at Coatbridge Technical School.

From 1906 to 1909 he was with the firm of Sack at Dusseldorf, where he was engaged on the design of rolling mills, the preparation of tenders and superintendence of plant erection. Returning to his native country in 1909, Mr. Wood joined Wellman Seaver and Head, taking charge of sales and plant erection in Europe. From 1914 to 1916 he was in H.M. Forces, but was recalled to take up work with his old firm.

In 1922 Mr. Wood was appointed British director of the Wellman Smith Owen Engineering Corporation, Ltd., as the company had then become, and of its associated company the Wellman Seaver Rolling Mills Company. In this capacity he was particularly concerned with steel works cranes and other plant, and with equipment for coke ovens. He was a Member of the Institution of Mechanical Engineers, to which he was elected in 1922. Mr Wood retired from the Wellman Smith Owen Engineering Corporation in December, 1951.

British Standards Institution

All British Standard Specifications can be obtained from the Sales Department of the Institution at 2, Park Street, London, W.1.

EXTRA PRECISION BEARINGS

No. 3964 : 1960—Addendum No. 1 to B.S.292 : 1958. Price 3s. The tolerances on dimensions and running accuracies for extra precision bearings given in this addendum to B.S.292 apply only to bearings with metric dimensions. The tolerances, which are given in inch and metric units, refer to rigid single-row ball journal bearings, angular contact single-row ball bearings and rigid parallel-roller journal bearings. In due course, a separate British Standard will be issued, relating to instrument bearings, which require special dimensions and characteristics.

TOUGHENED POLYSTYRENE EXTRUDED SHEET

No. 3290 : 1960. Price 3s. Requirements are specified in this Standard for two types of toughened polystyrene extruded sheet: the plain type and the type faced on one side with a thermoplastic foil. Details are included of the required composition, dimensions with tolerances and physical properties. B.S. 3290 is one of the marks required to appear on containers of sheet purporting to comply with the standard. B.S.I.'s well-known certification mark, "The Kite," may also be applied if the manufacturer is licensed to use it.

LETTERS AND LITERATURE

Letters to the Editor

MILLIONS TO BE SAVED?

SIR,—so far as the former Metropolitan and District Railway is concerned Mr. J. R. Harding is wrong in assuming that I and the R.C.L. do not advocate conversion of the Underground ; indeed this portion of London's Underground electric railway system merits high priority in the conversion programme, especially the Inner Circle, which is a ready-made ring road for central London far superior in alignment and accessibility to any new ring road that has been mooted. It links all the main passenger termini north of the Thames, and from it the M. and D. lines spread their network reaching out to a dozen suburban and semi-suburban terminals ; these lines include three Thames crossings ; the whole would convert into a motor-road network of incalculable value. Its present value, as a rail network, is calculable. The Underground system has a revenue deficit of £11,000 per mile p.a., which means that its value is minus £200,000 per mile! The accompanying table of data, extracted from the accounts of London Transport for 1959, shows how the Underground has to be underwritten by London's eminently economic bus and motor-coach services.

	London Transport, 1959	
	Road Services	Rail Services
Capital employed, millions	£29·5	£107·1
Passenger-miles, millions	6,293	3,193
Fuel consumed :		
Road diesel oil, million gallons	30·5	Nil
Electricity, million units	142	595
Total coal equivalent, tons	274,000	337,000
Coal equivalent per million passenger-miles, tons	43·5	105·2
Net operating receipts, millions	£4·0	£2·0
Add : Fuel tax paid, millions	£3·8	Nil
Licence duties, millions	£·04	Nil
Gross payability, millions	£8·2	£2·0
Deduct : Share of B.T.C.'s central and capital charges, millions	£1·5	£4·5
Road wear, say, millions	£1·0	Nil
Net payability, millions	+£5·7	−£2·5

Equivalents : 267 gallons road diesel = 1 ton oil = 1·7 tons coal = 3000 units electricity.

It has often been declared authoritatively on behalf of London's bus services that their payability would rise by £2,000,000 a year if traffic congestion could be lessened sufficiently for the speeding up of their schedules by 1 m.p.h. This guarantees vastly greater payability for the bus services on the converted M. and D. routes, where the traffic will flow freely, with congestion eliminated by means of access control ; indeed the table provides, in itself, sufficient argument for the conversion. Moreover, it is not to be imagined that the Underground has become an incubus through being at all overburdened with capital charges ; the proposed new Victoria–Walthamstow line, 11 miles long and costing £55,000,000, would yield a 5 per cent increase in route mileage (226 miles) for a 50 per cent increase in capital ; thus it is clear that, in relation to present-day costs, the Underground was nationalised at a bargain price : it is an incubus in its own right.

For the benefit of those who are unfamiliar with the Metropolitan and District lines it is perhaps necessary to explain that they are misnamed Underground. They can be regarded as ordinary railways, except possibly the Inner Circle (13 miles), which is mainly of cut-and-cover construction ; it is truly tunnelled at only two points (Campden Hill 421 yards, and Clerkenwell 730 yards of twin double tracked tunnels) and, since it was constructed in the steam age, between 1861 and 1884, its open-air stretches are sufficiently frequent for natural ventilation, though no doubt extra ventilation would be required in places and the buses would best be powered by electric battery : battery weight would scarcely matter, for the only two gradients are a mere 1 in 100 for 1 mile and 1 in 70 for ¾ mile.

The great thing about the Inner Circle, compared with foreign urban motorways, is that every ½ mile or so along it there is a station providing ready-made access for the bus passengers and also potential access for the permitted classes of vehicular traffic—perhaps cars, taxis, and light vans only. Access could readily be controlled to give the buses due priority at rush hours ; and if the traffic were then to flow at no more than 35 m.p.h. it would still be more than three times as fast as the street traffic up aloft, and twice as fast as the present trains, which necessarily stop at every station. Indeed the Inner Circle is greatly wasted as a railway. Moreover, with the growth of population, its rush-hour trains are fast qualifying to claim the world record, held by an historical Black Hole, for incarcerating human beings "bunched like asparagus"—Earl Baldwin's classic phrase. This analogy will cease to be apt when buses replace the trains, for bus services have a very much higher capacity than rail services under comparable conditions, as I showed in a letter you kindly published on July 20, 1960.

T. I. LLOYD

Guildford,
February 18, 1961.

SIR,—It is impossible to let "the facts" quoted in T. I. Lloyd's letter of February 5 go unchallenged. The 20,000 passengers mentioned presumably caters for those from the Guildford area only, as the Southern Region line carries more than 400,000 daily to and from London in the rush-hour. Mr. Lloyd claims greater frequency of service after rail conversion, but the few figures he does quote bear no relation to the facts, as can be seen from the following factual example.

During the rush-hour the South-Eastern Section of the Southern Region handles fifty-four trains an hour with a capacity of 60,000 passengers through London Bridge Station on three tracks. In terms of Mr. Lloyd's forty-seater buses this requires an average of one bus per track every 7½ seconds, which is sixty times the frequency quoted by Mr. Lloyd.

Finally the standard clearance through tunnels and bridges is 26ft 6in for a double track, which will only yield two 12ft wide M.O.T. traffic lanes, despite any calculations.

N. PALLETT

London, S.E.6,
February 17, 1961.

METROPOLITAN LINE WIDENING

SIR,—I read in your pages two or three years ago of an arrangement adopted in France whereby the direction of travel along certain important railway tracks was capable of being reversed to suit the varying needs of the traffic. This is really only an adaptation of the principle of single-line working, but in the particular instance quoted there were, I believe, four parallel tracks which, instead of being reserved two for "up" traffic and two for "down" traffic in the conventional way, were capable of being used to carry three or four "up" trains simultaneously or three or four "down" trains.

This principle would seem to have considerable value for suburban lines with their heavy "up" traffic in the morning rush-hour and "down" traffic in the evening. In particular it would appear to have offered an exceptional opportunity for reducing costs of London Transport's £9,000,000 scheme for improving the Metropolitan Line, which includes the widening of the line between Harrow and Moor Park from two tracks to four.

The traffic on this line, which is almost entirely suburban, is shared between London Transport working out of Baker Street, and British Railways working out of Marylebone. The provision of four tracks to Moor Park would make it possible to segregate the two services completely, but this is apparently not to be done and a mixed service of L.T.E. and B.R. trains is to be continued.

This being the case, it would appear that an equally good service could have been given by the building of only one additional track between Harrow and Moor Park instead of two. This would have given three tracks, the centre one of which could have been made reversible on the French pattern and could have carried the additional "up" trains in the morning and "down" trains in the evening. The traffic in the reverse direction is slight and could easily be carried by the single remaining track.

I am not in a position to estimate the saving which might have been made by adopting this principle, but I have no doubt it would have been considerable and would have been especially welcome in view of the present restrictions on capital expenditure. The four-track scheme is now well advanced. Is it possible, even at this late hour, to effect some saving by reverting to three tracks ?

E. J. R. KAY

Rickmansworth,
February 15, 1961.

Book Reviews

The Modern Airliner: Its Origins and Development. By PETER W. BROOKS. Putnam and Co., Ltd., 42, Great Russell Street, London, W.C.1. Price 30s.

THE name of the author will, for those interested in air transport who read the British technical press, be sufficient recommendation for this publication. (A companion volume, *The World's Airlines*, is in preparation, and is to give detailed technical and operating data for the most important machines in service to-day—we cannot resist remarking that if, as one may well expect, Mr. Brooks records not merely the facts that are easily ascertainable, but those that finally decide the operating weight, the cruising speed, the weather minima and the service lives—in short, those that spell success or failure—then it will fill a real need). So comprehensive is the present volume that no objection would be well founded were its title simply *The Airliner*. It is, in fact, only in Chapter III that there are reached "The Origins of the Modern Airliner," the Boeing "247" and the DC-1 of 1933, which exploited structural techniques of long standing, the cantilever wing and the monocoque fuselage, to improve radically their competitive ability; the basic Douglas Commercial configuration, the author shows, persists in production to-day in the D.H. "Comet." Douglas himself, however, was neither willing nor able to stay with the one successful design, as Boeing and then Lockheed were brought into competition by the struggle for traffic among air-lines selling seats at fares that left no margin for extravagance. If there is any adverse criticism to be made of the text, it is that the airliner is taken out of its environment, and that the economic facts of life, such as pooling, are overlooked; certainly the reader will find no explanation why British European Airways, a predominantly short-haul operator, possesses examples of an early-primitive jet transport originally designed for the North Atlantic route. Minor irritations are that the verb "to derive" is over-stressed—it is hard to contemplate it as applicable to any design of that uncompromising originator, W. B. Stout—that the term "total" costs is less happy than "direct" or "indirect," and that it is disappointing to see the Lippisch "Aerodyne" classed as a deflected-jet rather than a deflected slipstream flat-riser and therefore deemed "probably unsuitable for city centre operations." In view for the current fashion for extrapolating curves of speed on a base of time, it is distressing that the one in this text fits the points so loosely; this may be explained by the appearance of machines such as the "Elizabethan" (why not "Ambassador"? The "Pionair" is nowhere mentioned) and, in fact, if the curve is confined to the eleven transports of United States origin a smooth curve results, and the predicted speed for 1964 moves from 500 m.p.h. to 625 m.p.h. (Whitcomb, here we come!)

Those who are familiar with Mr. Brooks' detailed descriptions of individual designs may wish that the present text had probed deeper to explain why and how the engineers brought about their successes and, particularly, failures, such as the "fail safe" nature of the DC-3 wing and—a lesson obviously still unlearnt—the "Tudor" disappearances. Even more we wish that he, as one of the desperately scarce (in this country) pilots with an engineering training, had devoted himself to the handling qualities of the machines, a topic which, except inevitably in the case of the "Comet," escapes notice.

It must be recorded that the compilation of the volume by the publishers may appear ill-suited to the importance of the text and to the retail price. It is printed on paper of inadequate opacity in 8-on-10pt. Baskerville, the proof reading is such that the width of the North Atlantic is measured in seat miles, drawings bearing writing (in one case in a foreign language) are reproduced at a forbiddingly small scale and those with little information content unnecessarily large, the bunch of rather small photographs is disappointing (it contains not a "Britannia," a "Ukraina," or a "Rossiya"), and one would have been prepared to sacrifice one of two portrayals of the Zeppelin-Staaken E.4250 for, say, one of the distinctive Junkers G.38. The quality of the writing is such that it will be widely read for pleasure as well as duty, and a more attractive publication might well have reached many who have no connection with air transport but could well benefit by understanding something of this important industry.

Fluid Mechanics Through Worked Examples. By D. R. L. SMITH and J. HOUGHTON. Cleaver-Hume Press, Ltd., 31, Wright's Lane, W.8. Price 28s.

THIS is not the first book designed to assist the student of fluid mechanics (and his tutor) by providing both worked examples and further, unworked, problems. By itself it is a useful work, but the distinguishing claim that it is a "contribution from two leading Colleges," "reflecting the latest examination needs," outlining "very adequately the principles," is an unfortunate over-statement which cannot appear justifiable, particularly when read in conjunction with the senior author's preface which refers to Part I, II, or III of a degree in Engineering.

The book is likely to be of greatest use to students preparing for Higher National Certificate and similar examinations. These students, however, will require more explanation of the theory than is provided in the introductory notes of each chapter, and the addition of at least a brief bibliography in the next edition is recommended.

The publishers have designed the book so as to restrict the letterpress and the mathematical lines to a narrow column leaving an unusually wide margin in which the numerous sketches appear alongside the text referring to them. This arrangement appears excellent. The sketches are neatly drawn, and there are few mistakes. Altogether the book looks attractive and is pleasant to handle.

Symposium on Shaft Sinking and Tunnelling. Institution of Mining Engineers, 3, Grosvenor Crescent, London, S.W.1. Price £3 2s.

THIS record of the International Symposium on Shaft Sinking and Tunnelling, organised in July, 1959, by The Institution of Mining Engineers, provides a valuable addition to reference literature for mining engineers and students. At the symposium twenty-five papers were presented by authors from fourteen countries describing the techniques developed for shaft sinking and tunnelling in widely differing geological conditions. These techniques and plant were fully discussed by experts at the meetings, and the records of these discussions in the book are supplemented by written contributions which considerably enhance the value of the papers.

Books of Reference

Heat Transfer. By Alan J. Chapman. New York: The Macmillan Company, 10, South Audley Street, London, W.1. Price 63s.—This work was written for use in an introductory course on heat transfer for senior or first-year graduate students. It presupposes a working knowledge of differential equations and the fundamental principles of thermodynamics and fluid dynamics, although one chapter is devoted to a basic treatment of viscous fluid dynamics inasfar as this is pertinent to heat transfer. The section dealing with heat conduction includes those cases of one-dimensional conduction which are of interest to engineers, as well as extended surface problems. Transient as well as steady conduction in various geometric shapes which are of practical interest are treated. Use is made, where applicable, of Bessel functions and orthogonal sets of functions; their main properties are outlined in a special appendix. For the benefit of those principally interested in applying the results, these are presented in a simple graphical manner. Convection receives extensive treatment, with a discussion of basic thermodynamics and fluid dynamics (boundary layer theory). The principles of dimensional analysis are applied to this case. Radiant heat transfer is limited to cases of radiation and re-radiation between black or grey finite surfaces separated by a non-absorbing medium. Two chapters are devoted to conditions where more than one mode of heat transfer operates at the same time, including heat exchangers, thermometric errors, and the solution of certain classes of problem by reiteration. Because of the great importance in heat transfer of the physical properties of the materials involved, a special chapter is devoted to this aspect, and the thermal properties of a large number of technically important gases, liquids, and solids, are appended.

Surface Water Year Book of Great Britain, 1958–59. Surface Water Survey Centre, Ministry of Housing and Local Government. H.M. Stationery Office. Price 17s. 6d.—The latest edition of the *Surface Water Year Book of Great Britain* covers the water year 1958–59 and includes flow records of 188 river gauging stations, in most cases with related rainfall. A good many new stations have been established and have come into operation since the 1957–58 Year Book was published, but calibration has not yet proceeded far enough to warrant inclusion of their records.

The water year covered by this edition is of particular hydrological interest in view of the severe drought experienced during the summer of 1959. The rainfall over England and Wales during the last five months, May to September, of the water year was only about half the long average (1916–50) rainfall for these months and was probably the lowest for May to September for over 230 years. Most rivers reached abnormally low stages of flow by the end of September. The effect of this very dry spell is reflected in the unusually low "losses" indicated by comparison of the rainfall and run-off figures quoted in the Year Book.

The *Surface Water Year Book* is now published towards the end of each calendar year.

Books Received

Cermets. Edited by J. R. Tinklepaugh and W. B. Crandall. Reinhold Publishing Corporation, New York. Chapman and Hall, Ltd., 37, Essex Street, London, W.C.2. Price 76s.

Technische Schwingungslehre. Vol. 2. *Umbearbeitete und ergänzte Auflage*. By Karl Klotter. Springer-Verlag, Berlin-Wilmersdorf, Heidelberger Platz 3 (West Berlin). Price DM.58.50.

Lehrbuch der Hochspannongs Technik. By Guntram Lesch. Edited by E. Baumann. Berlin-Göttingen-Heidelberg: Springer-Verlag, Berlin-Wilmersdorf, Heidelberger Platz, 3. Price DM.39.60.

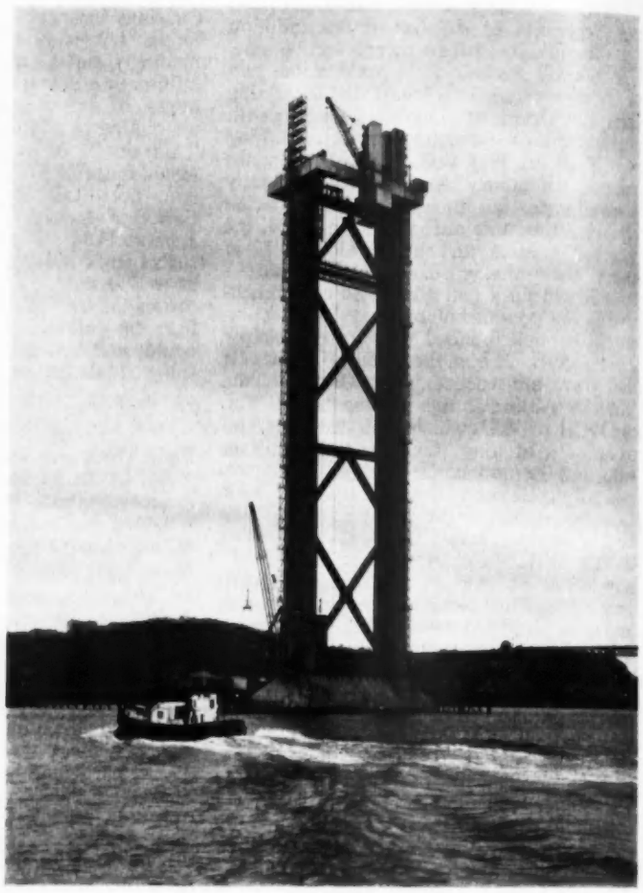
Research on the Rolling of Strip. A symposium of selected papers 1948–1958. The British Iron and Steel Research Association, 11, Park Lane, London, W.1. Free to BISRA members, or price 21s.

Einführung in die Technische Thermodynamik. By E. Schmidt. Eighth revised edition. Berlin-Göttingen-Heidelberg; Springer-Verlag, Berlin-Wilmersdorf, Heidelberger Platz, 3. Price DM.33.

Progress of the Forth Road Bridge

A DESCRIPTION OF THE SUBSTRUCTURE AND THE MAIN TOWERS

The Forth suspension bridge has been under construction for just over two years. The foundations of the main bridge are now substantially complete and erection of the steel towers is in progress. Our description is confined to these stages of the work, which have involved engineering methods of exceptional interest and novelty. On the right we show a recent view of work in progress at the north tower.



THE first really long-span suspension bridge to be built outside the United States is now taking shape at the Firth of Forth in Scotland, beside the famous railway bridge which was completed seventy years ago. The old Forth bridge will, in fact, still have the longest span in Britain until its neighbour is completed, when the two structures standing side by side will present an unrivalled spectacle for the connoisseur of structural form. The principal span of the new bridge will be 3300ft. The two long spans of the railway bridge are each 1700ft in length, and have been exceeded in Europe only very recently, with the completion of the Tancarville bridge in France.*

The design of the new Firth of Forth bridge is well shown by the elevation and cross section of the suspended structure illustrated opposite, and Table I lists some of the principal figures relating to it. Much interesting work is still to be done in erecting the superstructure of the bridge, but in this article we have limited our description to those parts of the main bridge which have already been built or where work is now in progress ; that is, the substructure of the main bridge and the two steel towers. Major constructional works are necessary to build the approach roads and viaducts serving the bridge, and earthmoving and other works are already well in hand at the site. However, no further details of these works are given here, except in the table.

*See THE ENGINEER, Aug. 14, 1959, page 82 and July 1, 1960, page 5.

TABLE I.—*Principal Data for the Forth Road Bridge*

Length of central span	3300ft
Length of each of the two side spans	1340ft
Southern approach viaduct :	
Number of spans	Eleven
Total length	1437ft
Northern approach viaduct :	
Number of spans	Six
Total length	827ft
Total length of bridge	8244ft
Length of approach roads :	
North side	6 miles
South side	3 miles
Details of main bridge :	
Height of two main towers above mean tide level	512ft
Length of main cables	7000ft
Diameter of main cables	2ft
Distance between centre lines of stiffening trusses	78ft
The deck consists of :	
Carriageways	Two by 24ft
Cycle tracks	Two by 9ft
Footpaths	Two by 6ft
Minimum clear height of deck above river	150ft
Quantities of steel in main bridge :	
High tensile steel in towers	6000 tons
Galvanised, 0·196in diameter, h.t. wire in cables	7,500 tons
Number of wires per cable	11,618
Steel in suspended structure	16,000 tons
Reinforcement in concrete	6,000 tons
Other steel elements	3,000 tons
Total	39,000 tons
Design loading :	
(*a*) Roadway	BS 153 HA loading Forty-five units HB loading
(*b*) Cycle tracks and footways	BS 153 footway loading
Principal quantities for approach roads and viaducts :	
Excavation	3,000,000 cubic yards
Concrete	90,000 cubic yards
Reinforcing steel	5,500 tons
Carriageway surfacing	350,000 square yards
Estimated cost of entire project	£15,500,000
Estimated completion date	1963

See also "Firth of Forth Road Crossing," THE ENGINEER, February 15, 1957, page 257.

Several sites for a road crossing of the Firth of Forth were investigated thoroughly before the present one was selected. The railway bridge already occupies the ideal site ; a road bridge right beside it would have been objectionable aesthetically as well as introducing the problem of aerodynamic buffeting, a very undesirable complication which had to be investigated quite recently for the Runcorn-Widnes bridge.† The difficulty of the site also led to two other proposals which were each the subject of certain researches and design studies before they were eventually discarded. One suggestion was to build a single carriageway road on a structure carried above the rail tracks of the railway bridge. The other, comparison of which with the proposed bridge was investigated by a panel of engineers appointed by the Ministry of Transport, envisaged a subaqueous reinforced concrete "tube" carried on large diameter piles above the bed of the Forth. This latter proposal was described quite fully in the article referred to in Table I.

The site finally chosen was the one which was considered to meet as far as possible the somewhat conflicting requirements of economics, good foundation conditions, freedom from major constructional hazards, aesthetics and suitable alignment for the approach roads. In particular an excellent foundation on solid rock and in relatively shallow water was offered for the north pier by the Mackintosh Rock—a massive ledge about a quarter of a mile from the shore.

†See THE ENGINEER, May 13, 1955, page 654.

From the Mackintosh Rock the rock slopes steeply to the deepest part of the Forth but on the south side it falls more gradually and is largely overlain by a thick deposit of boulder clay, gravel and silt. The position chosen for the south pier offered founding rock at a considerable depth, but this was not thought to be excessive for caisson construction in view of the stability and impermeability of the overlying boulder clay.

The configuration of the ground and rock on each shore and the great height of the bridge roadway resulted in the decision to use tunnel anchorages in conjunction with side towers (on which are main cable turning points) rather than concrete gravity structures.

The substructure works thus consist of (*a*) the north pier, built in cofferdam, (*b*) the south pier, built on caissons sunk to the rock, (*c*) two reinforced concrete side towers, one on each bank, which carry respectively the shore ends of the two side spans and the end spans of the approach viaducts, and (*d*) the cable anchorages which consist, on each bank, of two tunnels of large diameter filled with concrete. Prestressed steel cables are built into this concrete, and also steel seatings to which the strands of the suspension cables will be attached.

The main tower steelwork is of exceptional interest, being of high-tensile steel prefabricated elements weighing up to 35 tons ; all site joints are bolted, and a climbing ring-girder device is used to reduce the problems of erection to a relatively simple routine.

The bridge is being constructed for the Forth Road Bridge Joint Board, a body set up by parliamentary legislation (The Forth Road Bridge Order Confirmation Acts 1947-58) to administer construction and subsequent operation of the bridge on a toll basis. Design and supervision of construction is in the hands of the consulting engineers, Messrs. Mott, Hay and Anderson, with whom are associated Messrs. Freeman, Fox and Partners. The substructure works for the main bridge have been built by John Howard and Co., Ltd., the substructure contract being valued at £2,200,000. The superstructure is being erected by the A.C.D. Bridge Company on a target contract valued at £8,660,000. This firm is a consortium of Sir William Arrol and Co., Ltd., the Cleveland Bridge and Engineering Co., Ltd., and Dorman Long (Bridge and Engineering), Ltd. all three member firms sharing both manufacturing and erection responsibilities. A road crossing of the Firth of Forth has been seriously considered as an engineering project since 1926, when Messrs. Mott, Hay and Anderson were appointed consultants for the bridge.

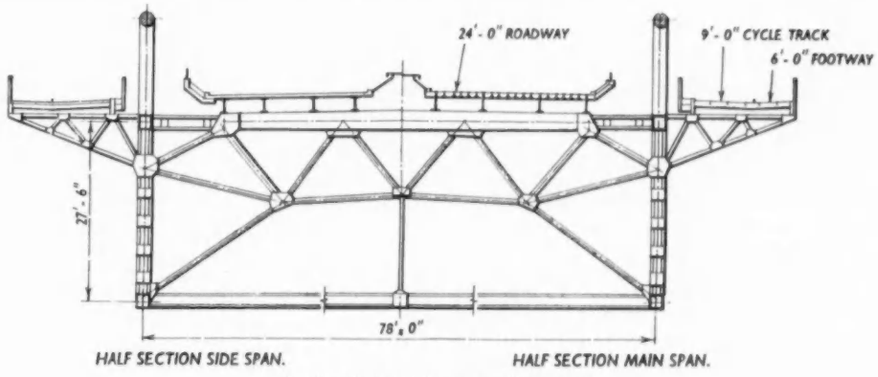
The South Pier

For each main pier, a rock causeway and a welded steel- and timber-piled gantry were built out into the river to close beside the site of the pier to give direct access, both for construction of the pier and subsequently for bringing the tower steelwork for erection. These two embankment and gantry constructions are quite sizeable jobs in themselves.

The method planned for the construction of the south pier had to take into consideration not only the favourable properties (mentioned above) of the clay overlying the rock, but the character of the other beds, including the upper deposits, and the fissured water-bearing nature of the rock which investigation had shown existed at a depth of about 100ft below datum. It was therefore considered advisable to provide for the use of compressed air in case the volume of water encountered proved too great to be pumped.

Construction of the pier is best explained by following through the series of diagrams on page 298. Two caissons, each 60ft in diameter, were required ; the work was thus on a very large scale, as can be seen by reference to the dimensions and levels noted on the diagrams. The first stage of the work involved the building of a temporary cofferdam large enough to contain these two caissons, and with sufficient penetration to be sealed into the clay.

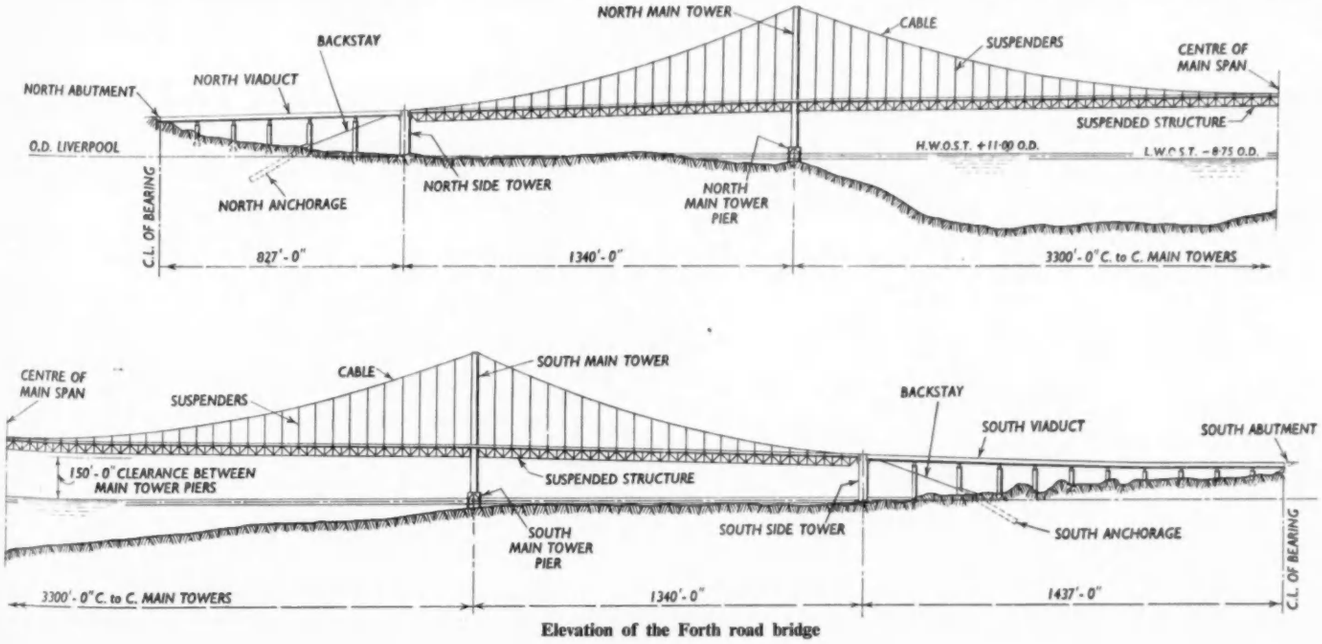
A steel-framed waling shaped like a figure-of-eight was first constructed on a staging on the north foreshore. The two circles were each 85ft in diameter, and were formed at the lower level of the frame by watertight welded steel box members of 4ft by 2ft 6in cross section in ½in thick steel plate. These box members gave the frame buoyancy, so that it could be floated out into position. A similar figure-of-eight was formed at the top level of the frame by a braced girder assembly, the two being interconnected by a Warren bracing to form a frame with a depth of 16ft. The total weight of steel in the complete figure-of-eight waling frame was 105 tons.



Sectional views of suspended structure

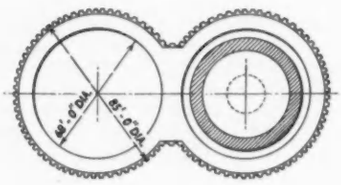
The frame was towed into its working position on the south side on an exceptionally calm day. It was then held against steel box piles driven into the river bed, the box-member was punctured to destroy its buoyancy, and the frame seated at its final level. A curtain of steel-sheet-piling was then driven round the frame, to a penetration of 15ft into the boulder clay. The sections of piling used were Larssen 4B and A-F.5.

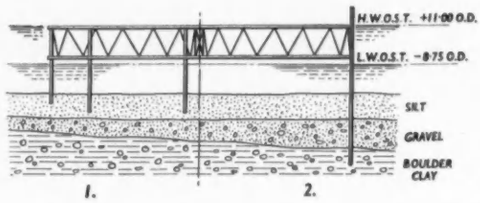
With the steel-sheet-piled enclosure formed, sand and silt were excavated, by grabbing, to a level of −36 O.D. Then circular shutters 16ft in height, leaving two clear circular spaces inside each 68ft in diameter, were

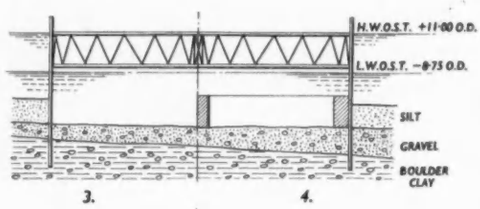


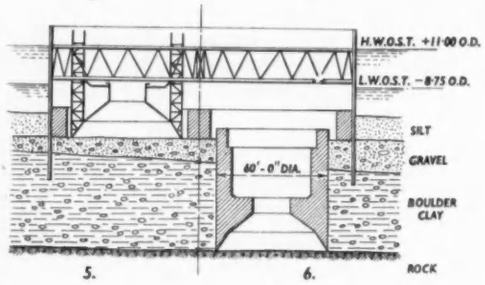
Elevation of the Forth road bridge

Constructional Sequences at Main Piers



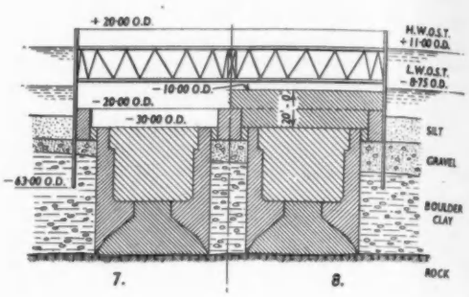


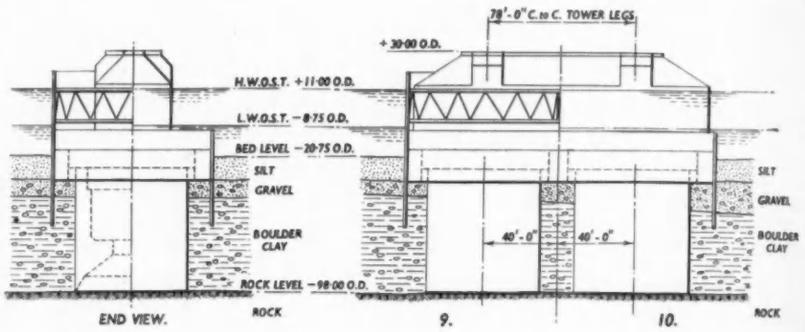


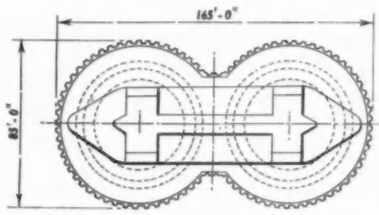


STAGES IN CONSTRUCTION:—

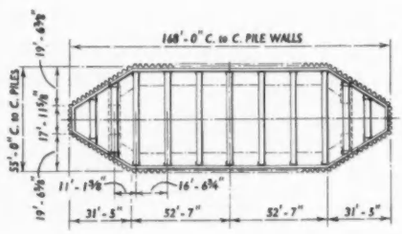
1. FLOAT IN FRAME, SUPPORT ON LEGS.
2. DRIVE SHEET PILES OF COFFERDAM.
3. GRAB OUT SAND AND SILT UNDER WATER TO −36FT. O.D.
4. CAST CONCRETE WALING UNDER WATER.
5. DE-WATER, ERECT STEEL CUTTING EDGES.
6. SINK CAISSONS THROUGH BALLAST AND BOULDER CLAY AND EXCAVATE INTO ROCK (UNDER COMPRESSED AIR IF NECESSARY).
7. FILL CAISSONS WITH CONCRETE.
8. CAST CONCRETE CAPPING SLAB.
9. CONSTRUCT PIER SUPERSTRUCTURE.
10. CUT OFF PILES AND REMOVE COFFERDAM.





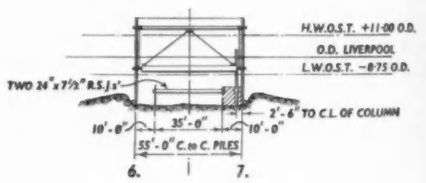


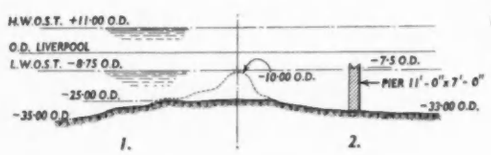
SOUTH MAIN PIER.

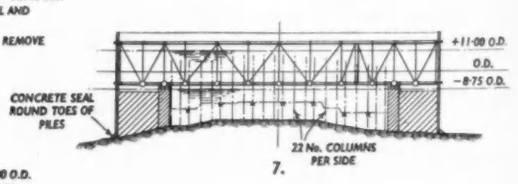


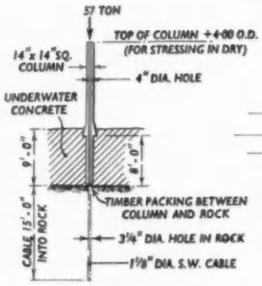
STAGES IN CONSTRUCTION:—

1. REMOVE ROCK ABOVE −25FT. O.D. BY BLASTING.
2. CONSTRUCT FOUR PIERS IN SHEET PILING, FILLED WITH INTRUSION CONCRETE TO −7·5FT. O.D.
3. FLOAT IN FRAME, SUPPORT ON CONCRETE PIERS.
4. ERECT STEEL SHEET PILES AROUND PERIMETER OF FRAME.
5. SEAL BOTTOM OF PILES IN CUTWATER ENDS, CLEAN OUT AND FILL WITH UNDERWATER CONCRETE.
6. CLEAN 10FT. WIDE STRIPS ON SIDE WALLS, SET INTERNAL SHUTTERS 9FT. HIGH FOLLOWING ROCK PROFILE.
7. SET 14" x 14" CONCRETE COLUMNS, PLACE CROSS BRACING JOISTS AND "TREMIE" CONCRETE 10FT. WIDE WALLS.
8. DRILL 15FT. INTO ROCK THROUGH HOLES IN STRESSING COLUMNS; INSERT 1⅛" DIA. S.W. CABLES AND GROUT IN ROCK. STRESS TO 57 TON PER CABLE.
9. PUMP OUT COFFERDAM.
10. LEVEL ROCK IN STEPS AND FILL WITH CONCRETE TO −10FT. O.D.
11. CUT OFF STRESSING COLUMNS ABOVE "TREMIE" WALL AND RESTRESS CABLES.
12. CONSTRUCT PIER SUPERSTRUCTURE TO +30FT. O.D., REMOVE FRAME AND CUT OFF SHEET PILES AT −10FT. O.D.

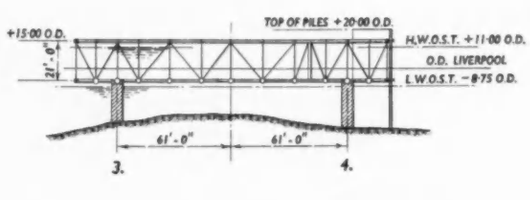


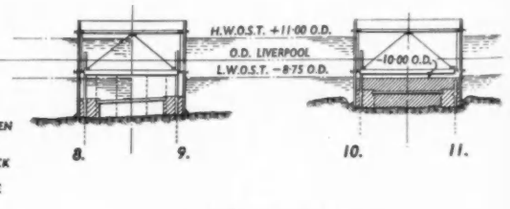


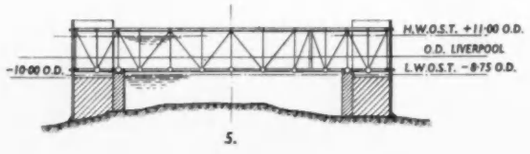




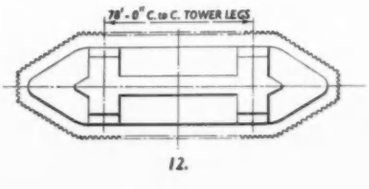
STRESSING COLUMN.







NORTH MAIN PIER.



built, and lowered on to the level base. The space between the shutter and the steel sheet piling was filled with coarse aggregate, and colloidal grout pumped into it. This shutter comprised two steel-framed drums with verticals lagged with timber, the steel frames being incorporated in the concrete as reinforcement. Thus a massive figure-of-eight waling of "intrusion" concrete was formed under water. With the bracing provided by this waling and the upper steel waling frame, the cofferdam was sturdy enough to be dewatered. The principal forces in the cofferdam walings are compressive but, due to the fact that the circular shapes were interrupted and connected by a rigid cross member, bending stresses had to be allowed for as well.

An important factor in the stability of the cofferdam was the band of clay forming in effect another "waling" below the excavated level within the cofferdam. The boulder clay at the Forth is a very stiff material, capable of standing unshored for some depth; in places it has a shear strength in the range 3000 lb to 5000 lb per square foot. Thus

The figure-of-eight waling at the south pier site, prior to sinking, as it was in June, 1959

with 15ft of penetration, the toes of the sheet piles were firmly supported.

The steel cutting edges of the two 60ft caissons were then constructed on the floor of the cofferdam, and sinking was started. When the caissons had penetrated some distance into the clay, bores were sunk to determine the quantity of water likely to be met at the rock surface. This proved to be quite small (easily handled by a 4in pump in each caisson) and so the sinking was completed without undue difficulty in free air and ahead of schedule. Needless to say provision was made for the use of compressed air if necessary, and one of the illustrations shows the man shafts and materials shaft positions on the caisson.

The steel cutting edge of each caisson was designed to resist an inward radial force of 15 tons per foot run. It had a clearance of 2in outside the main body of the caisson above it, to ensure free sinking. The annular space which thus formed above the cutting edge as the caisson descended was filled with bentonite. When the sinking was complete the bentonite was displaced with cement grout. The caisson was designed as a reinforced concrete structure, but with the addition of a steel skin in case conditions had proved unfavourable.

Excavation within the caissons was mechanised as much as possible, since the clay is such a hard and intractable material. The excavator shown at work in the caisson chamber in one of the illustrations was fitted with tines to loosen the clay, prior to using a bucket to load it into skips.

Both caissons were founded horizontally with negligible errors in level and alignment. Control of sinking in the early stages is considered to be essential in maintaining alignment and horizontality. The sketch on page 301 shows diagrammatically how this control was achieved. Concrete wedges about 5ft in length were placed at intervals round the diameter, and the cutting edge rested on them. Holes were left in the steel skin of the cutting edge, and reinforcing rods inserted through them, so that reinforced concrete ledges could also be built at intervals round the caisson. A concrete ring, also connected to the cutting edge by reinforcing rods but separated from the concrete ledges and wedges by paper joints, completed the arrangement. To sink the caisson it was necessary to excavate gravel from under the wedges and rings, a well-controlled process. As sinking proceeded the inner parts of the wedges were removed by blasting; then, later on, a further section of the concrete was blasted away; and finally, all the concrete was removed, level descent of the caisson to line having by this time been established.

When the rock was reached it was found to be uneven in level; where it was low, the cutting edge was supported on reinforced concrete walls. Then the working chamber was concreted. The space above it contained by the caisson walls was filled with whinstone boulders bound together with a weak concrete. Finally, a slab of reinforced concrete 20ft thick was constructed at the levels shown, extending over the tops of the ring beams to the steel sheet piling.

A shaped pier with cutwaters was then built on this slab. Holding-down bolts for the steelwork of the tower were cast into the pier, a complicated assembly of twenty-eight bolts 2¾in in diameter being positioned at each side of the two legs of the tower. The bolts extend to a depth of 13ft in the concrete, which is of high quality (6250 lb per square inch minimum compressive strength at twenty-eight days) and is heavily reinforced in this region.

Additional stability was given to the pier by prestressing it vertically on each side of each leg of the tower. Before the deadweight of the cables and suspended structure is added at the top of the tower, high winds may induce tensile reactions on one side of the legs. Hence the prestressing cables, which extend down to anchorages in the grouted masses in the centres of the two caissons. There are twelve cables at each of the four positions corresponding to the groups of bolts, stressed at the surface anchorage, with a prestressing force of 200 tons per cable. Table II gives some further data.

TABLE II.—*Loading Conditions at South Pier*

Total dead load on pier	19,000 tons
Total live load on pier	3,000 tons
Average pressure on rock at base of caisson	12 tons per square foot

The upper part of the pier is faced with an aggregate finish of pink granite. This finish is used on all the prominent plinth surfaces of the bridge. It is constructed by the "transferred aggregate" process developed by the Cement and Concrete Association. The aggregate is stuck on to the shutter by hand, using a cellulose and sand adhesive. Later on, when the shutters are struck, the adhesive is washed off, to leave a face of hand-picked stone.

The figure-of-eight frame was removed, and the steel piles burned off to complete the pier.

THE NORTH PIER

Contrary to expectation, the north pier proved less straightforward than the southern one. The second sequence of diagrams on page 298 explains its construction.

First of all the humped shape of the Macintosh rock was levelled by blasting and excavation under water. Here the first difficulty was met when an old wreck was discovered, and had to be removed.

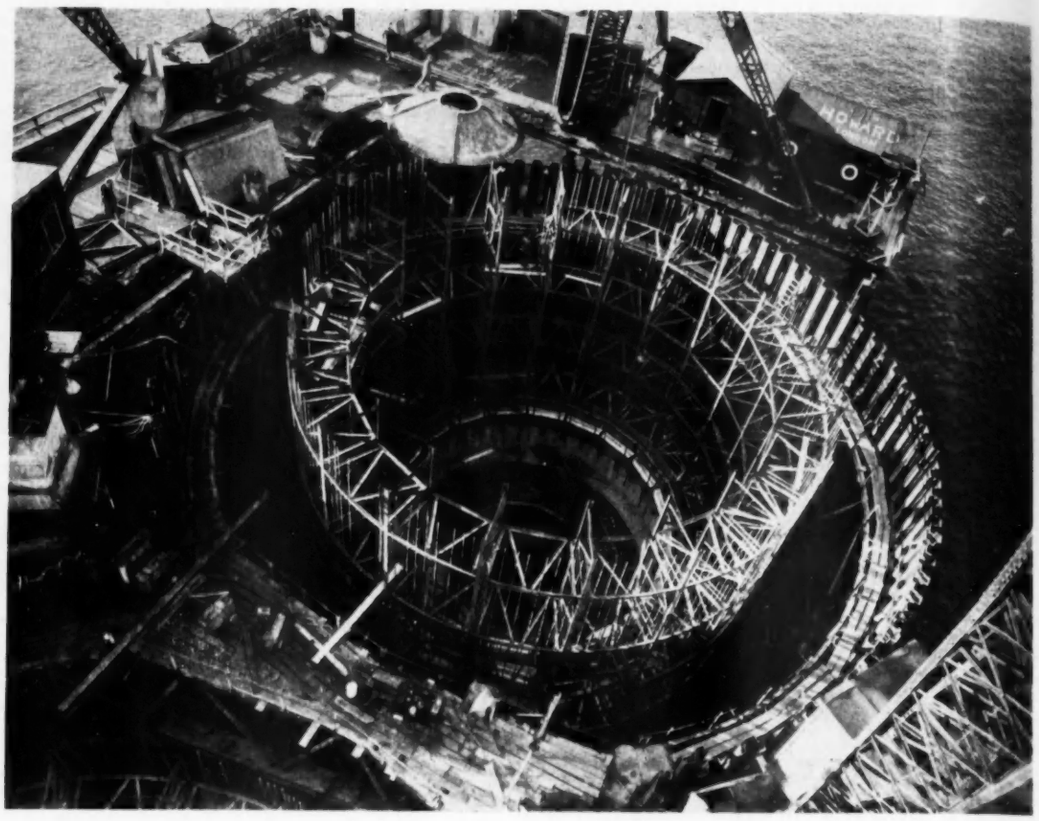
A cofferdam frame somewhat similar to the figure-of-eight frame used at the south pier was again employed, but in this case it was of simpler construction and shaped to enclose the dimensions of the north pier as given in the diagrams. Four temporary piers were built by driving boxes of steel-sheet-piling and filling them with "intrusion" concrete. The north pier frame was then floated out and fixed on these four piers. When it was in position, the tubular members providing buoyancy were punctured, and then steel-sheet-piling was placed round the periphery of the frame. Floating the frame out saved time by obviating the tide work needed to build a frame *in situ*.

Sealing the cofferdam at the junction of the rock and the steel-sheet-piling proved to be a second difficulty. The procedure adopted, therefore, was to seal just the cutwater ends of the cofferdam (by placing rubble and injecting it with colloidal grout) and the cutwater ends were then filled with "intrusion" concrete (i.e. coarse aggregate followed by colloidal grout) as shown in the diagram at stage 5, up to the positions of the temporary piers. This form of construction, however, was not considered satisfactory for the main area of the pier within the cofferdam, an area which had necessarily to form the permanent core of the north pier where concrete of uniformly good quality was needed.

A rock surface 10ft wide was therefore prepared by divers, along the inside of each wall of steel piling; that is a length of about 120ft on each side. Then a shutter 9ft high was set beside this cleaned rock, under water, and a heavy beam, 10ft wide by 9ft high, was formed by placing concrete by "tremie." Considerable thought and care was given to this operation so as to achieve a concrete of good quality.

A series of reinforced concrete columns was cast into this concrete, each with a central vertical hole; and cross-struts of structural steel, each a pair of 24in by 7½in R.S.J.'s, were positioned between the two beams before emplacement of the concrete.

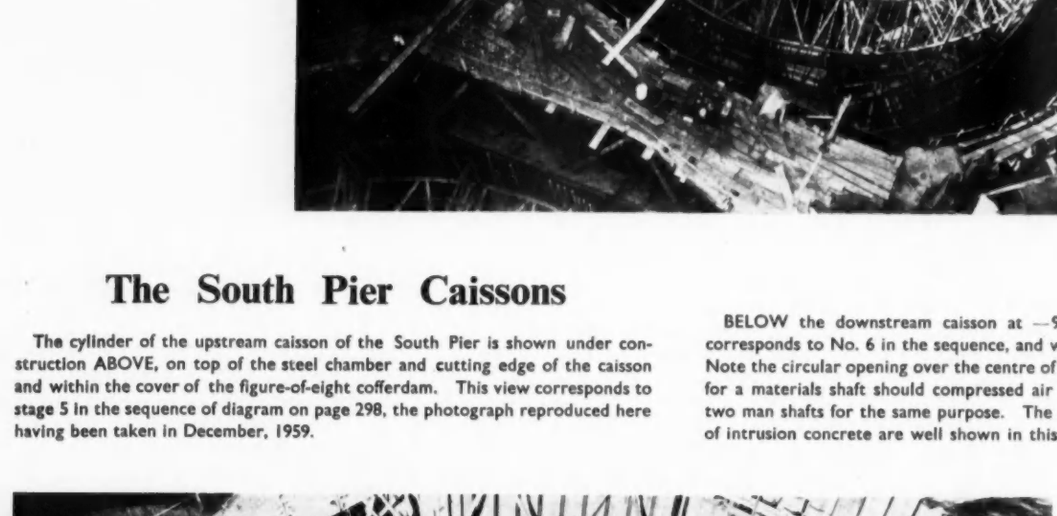
The columns extended above ordnance datum; after the "tremie" concrete had set, holes were drilled into the rock below, though the holes in the columns, to a penetration of 15ft. Cables were then inserted into the rock, and grouted in; the cables could then be prestressed from the column heads, thus anchoring the two big beams of "tremie" concrete to the rock. There were twenty-two of these columns on each side of the cofferdam, each prestressed with a load of approximately 57 tons, giving a total vertical loading of 2500 tons on the pier. The principal



The South Pier Caissons

The cylinder of the upstream caisson of the South Pier is shown under construction ABOVE, on top of the steel chamber and cutting edge of the caisson and within the cover of the figure-of-eight cofferdam. This view corresponds to stage 5 in the sequence of diagram on page 298, the photograph reproduced here having been taken in December, 1959.

BELOW the downstream caisson at —95·5ft o.d. This stage of progress corresponds to No. 6 in the sequence, and was reached in February of last year. Note the circular opening over the centre of the caisson chamber, with provision for a materials shaft should compressed air have been necessary, and also the two man shafts for the same purpose. The steel waling and the massive waling of intrusion concrete are well shown in this view.



Excavator working inside chamber of downstream caisson in hard boulder clay, with the cutting edge at —60·5ft O.D.

purpose of this prestressing was to anchor the two beams of "tremie" concrete, thus checking leakage under them, and also preventing instability due to hydrostatic uplift pressure.

With the massive support given by the concrete beams, anchored to the rock and strutted apart, it became possible to dewater the cofferdam. The "tremie" concrete could then be inspected and tested, to see whether the high quality sought had actually been achieved.

Inside the cofferdam, the rock was levelled in steps and then concrete was placed to fill the whole of the cofferdam up to the level —10ft O.D. At this stage the cables in each of the columns were released, in turn, and each column was cut off at the level of the top of the concrete slab. A new anchorage was made here, and the cable was then stressed again, this time permanently. Now the shaped pier could be constructed up to the base level of the tower, in the same manner as already described for the south pier, the temporary frame removed, and the steel-sheet-piles burned off.

The north pier also has prestressing cables placed close beside the anchorage bolts for the steel structure, which resist upthrust due to wind loading during construction while the tower is in a "free standing" condition. However, the prestressing put into the pier through the columns and anchorage holes into the rock is different in function in that it stabilises the pier as a whole. The pier is founded at quite a high level, and these cables solidly join it to the upper regions of the rock.

The loads on the south pier are the same as those already listed for the north pier, except for those given in the text for the rock anchorages.

Side Towers

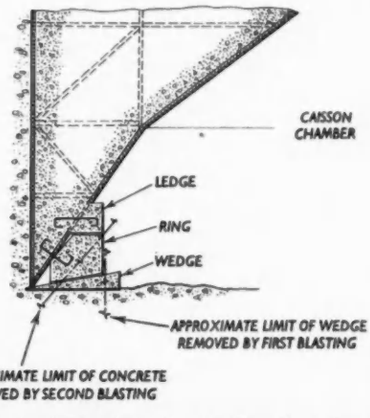
The side towers are massive reinforced concrete structures of cellular construction, with walls 2ft thick and horizontal diaphragms. They are founded on spread footings : on the south side, the tower is at the water's edge and was built inside a steel-sheet-piled cofferdam. Each tower is about 150ft in height ; the two are practically identical, their form being well shown by the illustration on page 303.

At the top of each of these towers steel saddles are to be provided, to deflect the line of the main cables down to the anchorages as shown in the elevation of the bridge. The vertical component of the resultant thrust transmitted from the cables to these saddles is about 4000 tons per cable. Considerable side loads are also possible at these towers due to wind loading on the bridge, and also longitudinal loads due to temperature and tractive forces in the approach spans and in the suspended structure of the main bridge.

The reinforced concrete of the towers is adequate for these loading conditions, but to give additional vertical durability and toughness prestressing cables have been built into them which are anchored in the bedrock below. There are eighty cables in each tower, each cable being tensioned to 120 tons. They are anchored in holes drilled to a depth of 45ft in the rock below the towers, using the Coyne method of anchorage. The Cementation Company was the sub-contractor for this operation.

The base of each tower is faced with precast concrete slabs faced with pink granite using the "transferred aggregate" process referred to earlier. Above the stone finish, the towers are to receive a special surface treatment.

Construction of the towers was carried out by building a steel tower inside the leg of the permanent tower, which supported a cathead. Shuttering panels for the walls were hung from the cathead, which was raised by jacks after each lift was completed, and then further scantlings were inserted in the steel tower. The latter was left in place ; it also braced the tower of a crane, also placed centrally but rising to above the full height of the construction, and used for placing the concrete. The diaphragm floors of the tower legs were concreted after the walls had been completed. A massive trussed centering carried the soffit of the arch of the tower. The shuttering was designed by Mr. C. Parry to the main contractor's plant requirements.



Sketch showing method of controlling the caisson cutting edge during the early stages of sinking

Cable Anchorages

The method of cable anchorage is believed to be an innovation in suspension bridge construction, in that prestressing is utilised. Each cable will pass over a splay saddle at about ground level, which increases its angle of inclination on the anchorage side, and from which the individual strands splay out. There will be thirty-seven strands in each cable, each one passing round a steel strand shoe on the face of the anchorage. Individual wires will be threaded round these shoes when cable spinning is in progress. The strand shoes are held by links which are connected to the cables embedded in the concrete of the anchorage tunnels in the manner shown in the illustration.

Each anchorage is a gigantic plug of concrete filling an inclined tunnel in the rock, the tension in the main cable being transmitted to the concrete by 114 wire ropes or cables which are individually secured at their upper and lower ends and also grouted into the steel tubes through which they pass. Before being finally secured and grouted these ropes were stressed to a load greater than that which will be imposed upon them when the bridge is completed. By thus practically eliminating future movement at the head of the anchorage the adjustment of the cable strands as they are being spun will be facilitated and the deflection of the completed suspension system reduced. Details of the two anchorages are shown on the folding inset Plate, facing page 304.

The two tunnels on the north shore were excavated largely in whinstone rock, generally of good quality but heavily fissured ; they are wedge-shaped, the maximum span of the tunnel roof being 40ft. Care had to be exercised in making the roof secure, for which purpose a considerable number of roof bolts were installed.

On the south shore, the two tunnels were constructed in shale, a more treacherous rock decomposing slightly on exposure and giving a wet excavation. The cross sectional shape of the two tunnels on the south shore was made circular, as shown in the inset Plate. Just below the horizontal centre line of this circular tunnel, which was 25ft in diameter, concrete haunches were built. The tunnel above them was then lined with sheets of steel, ¼in thick, flanged and bolted to form a continuous skin abutting on the concrete haunches. The space behind the steel plate was grouted. The diameter of these tunnels was increased in steps at their lower ends. At the base, where the diameter is 45ft, construction was by mining methods from the shaft sunk between the two tunnels. The vault was first excavated and concreted, and then the "dumpling" was dug away.

Construction of these four tunnels was a large scale operation (the principal dimensions are given in the drawing) involving excavation to the extent of 28,000 cubic yards, and the placing of 27,000 cubic yards of low-heat concrete.

For each of the wedge-shaped anchorages on the north side, the cable pull is resisted by the weight of the wedge and of rock above it, and by shear in the rock. At the south anchorages, the pull is resisted by the "collars" where the tunnel diameter increases, again by gravity and by shear in the rock.

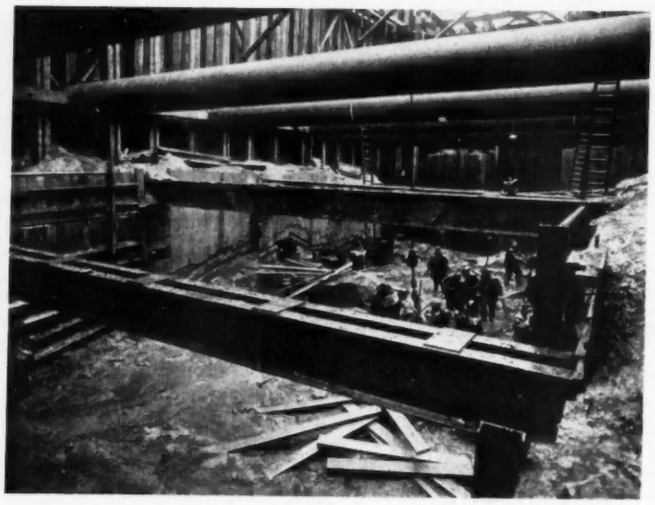
In each of the four tunnels, 114 cables, each comprising four 1¼in diameter strands, were threaded through ducts, and tensioned to a load of 150 tons, thus giving a total prestressing load of 17,100 tons in the anchorage. The corresponding tension from each main cable of the bridge will be 12,200 tons for the deadweight of the bridge, plus 1600 tons for live load.

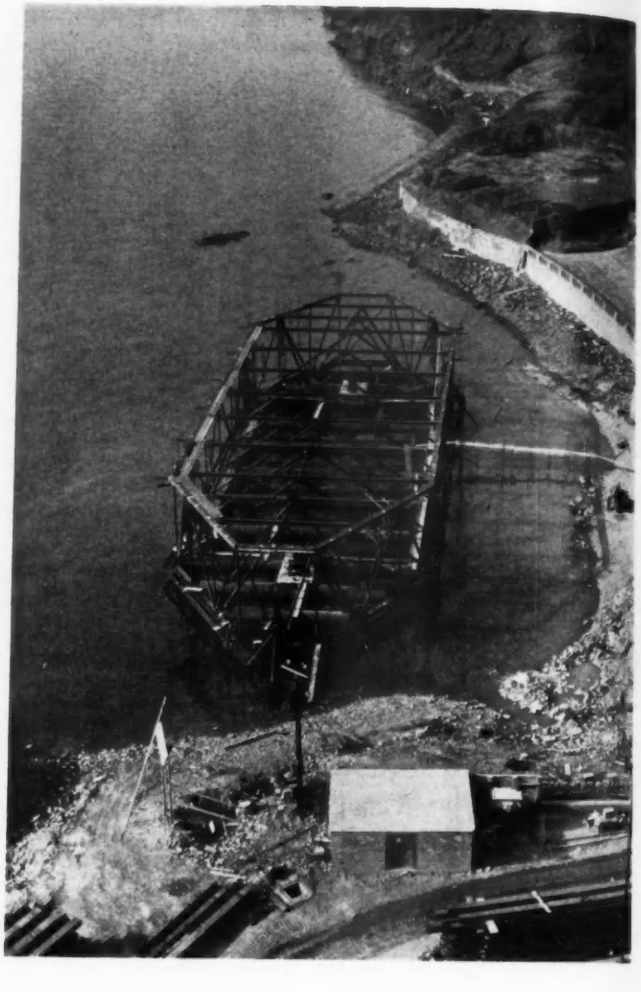
Constructing the North Pier

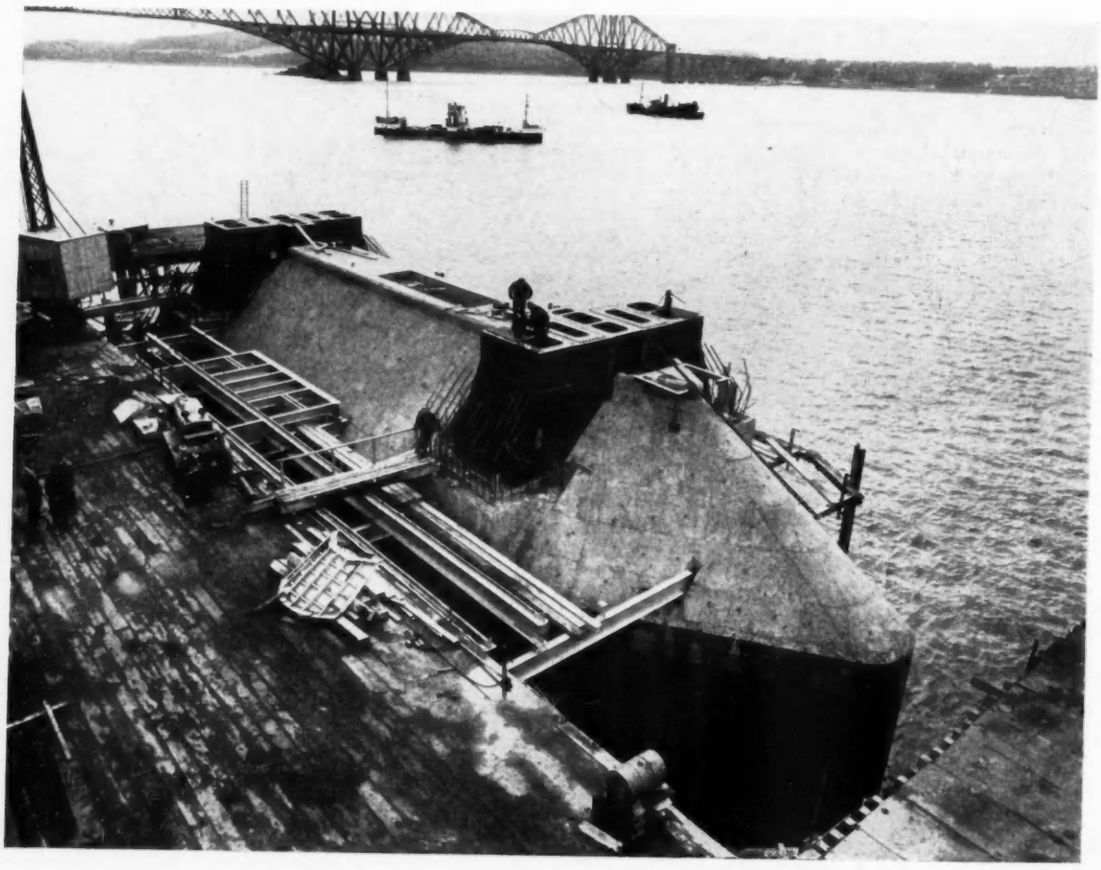
The cofferdam frame for the north pier is shown RIGHT, as it was in September, 1959, ready to be floated out to the north pier site ; i.e. stage 3 of the sequence on page 298.

The north pier cofferdam is shown dewatered LEFT, at the stage of construction reached by March of last year. Note the side walls of "tremie" concrete strutted apart by pairs of steel joists which had been placed in position before pouring the "tremie" concrete, i.e. as explained at stages 7 to 9 on page 298. The tubular struts in the upper part of the illustration formed the base of the floating frame.

The north pier is shown almost complete in the lower view, as it was last July. The exposed aggregate facing slabs can be discerned, and a good idea is given of the method of joining the steel tower to the pier. The base section of each tower leg—which is shown in detail in one of the drawings in the folding Plate—is in position on its holding down bolts, but has not yet been concreted in.







The south side tower nearly completed, showing progress made by last September

At the top end of the tunnel the prestressing cables are splayed out into their wires which are contained inside steel sockets, the latter being filled with molten zinc to embed the cables. The prestressing and grouting was done from the bottom end of the tunnel, and on each bank the vertical shaft and cross tunnel gave access to the two chambers where this work was carried out. Each strand was extended by a hydraulic jack, and then held by grips consisting of split cone-shaped wedges bearing in a steel casing, the four strands to each cable being stressed simultaneously. On completion of the stressing and grouting, the chambers are to be filled solid with concrete.

The Steel Towers

The main towers of the bridge are being constructed of high-tensile steel, prefabricated into large box-like elements, each weighing up to nearly 35 tons. The site joints are made by high-tensile bolts. This method of construction is considered to be an advance in suspension bridge practice, resulting in a saving in the weight of steel in the towers for a given duty, and in more rapid and convenient erection. Site work is reduced by the large size of the elements and by the use of bolting. Furthermore a climbing device, known as the "ring structure" is employed for erection. As can be seen from the drawing on the folding Plate facing page 304, each main tower is composed of twin legs united by horizontal and diagonal bracing.

The overall height of the tower is 482ft above the concrete base, but the steel structure extends 10ft down into the concrete, giving it a total height of 492ft. The two legs are at 78ft centres. The cross section shows that each leg of the tower consists of three welded "boxes," the central one being larger than the other two, and the three being joined into five cells by bolted cover plates. In one leg of each tower a lift will operate from deck level to tower top in one of the cells enclosed by these cover plates.

It is the boxes which constitute the large prefabricated elements already referred to. The full height of the tower is reached with eleven sets of boxes plus a base section. The main elements vary in length between 35ft and 47ft 6in. Each element is an all-welded assembly with machined faces where the bolted joints are made. Stiffening members run through it longitudinally and there are transverse stiffeners and diaphragms at intervals, as illustrated in the typical box shown on the folding Plate. Generally, the steel plate from which the prefabricated elements are built varies between $1\frac{1}{8}$in and $\frac{1}{2}$in in thickness, but in certain situations plate up to $1\frac{1}{2}$in thick is employed. Practically all of this work is in high-tensile steel. For the diagonal bracings, the braces between levels 183·8ft and 380·6ft are in mild steel, the others in high-tensile steel. Allowance was made in calculating the dimensions of these braces for a shortening, under dead load, of 1in between deck level and base, and of 3·35in in the full height of the tower.

Fabrication of the steel towers is being carried out at the works of Sir William Arrol and Co., Ltd. A high order of accuracy has been necessary for this work and unusual means had to be taken to ensure this accuracy in what is necessarily a complicated and large scale operation.

Shop assembly of the tower steelwork is an important aspect of the work. The end flanges which eventually were machined to form meeting faces on adjacent boxes were drilled together before the boxes were assembled to ensure accuracy in mating the bolt holes. The welding procedure was devised to keep distortion to a minimum, but even so, some of the meeting faces had to be machined more than once.

For drilling the bolt-holes to fasten the cover plates to the boxes, at least three "lifts" of boxes were assembled together at any one time. In practice each leg of a tower was shop-assembled in two stages, on steel bearers laid out on the shop floor. It was then necessary to break down these assemblies, and reassemble only the larger central boxes of both legs and the cross bracing, so that the bolt holes could be drilled accurately. This latter assembly had to be done in two stages, because there was not enough floor space available to do it in one.

TABLE III.—*The Steel Towers*

Type of steel in towers	High-tensile, weldable quality to B.S. 968
Steelwork below bottom splice...	M.S. to B.S.15
Type of steel in bolts	H.T.S. to B.S. 970
Grip bolts	En 16 V
Corresponding nuts and washers...	En 15 R
Close tolerance bolts	En 16 R
Corresponding nuts	En 6 A
Holding down bolts	H.T.S. to B.S. 548
All threads	B.S.F. to B.S. 84
Quantity of steel in one tower ...	3,000 tons
Height of towers	512ft
Centre line distance of legs of tower...	78ft
Maximum vertical load on tower from cables	20,400 tons
Horizontal load on free standing tower due to 110 m.p.h. wind...	464 tons

It can be well appreciated that errors in planeness of the meeting faces, and of twist or tilt of one relative to the next, would be magnified in the full height of the tower. It is considered that a higher order of accuracy has been achieved in this work than is customary in structural steelwork practice. Tolerances were not stipulated in the specification, but every effort was made to ensure the highest possible standard. At present the north tower is well advanced. We are informed that errors in alignment and level at the top of the tower are expected to be negligible. Erection of the second tower has been started, and is due for completion by the end of April this year.

The working load on the completed tower is given in Table III. Horizontal loading is insignificant under these conditions, the ultimate load being an Euler load.

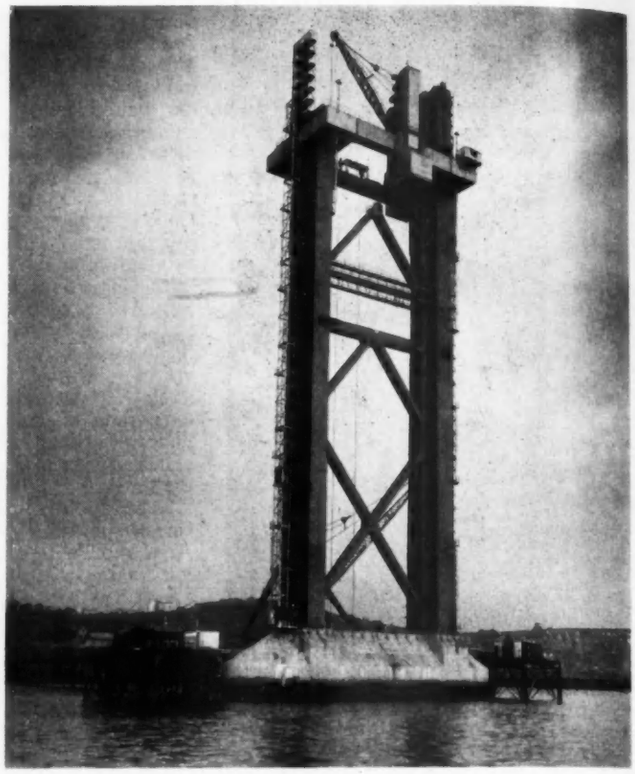
Erection of Towers

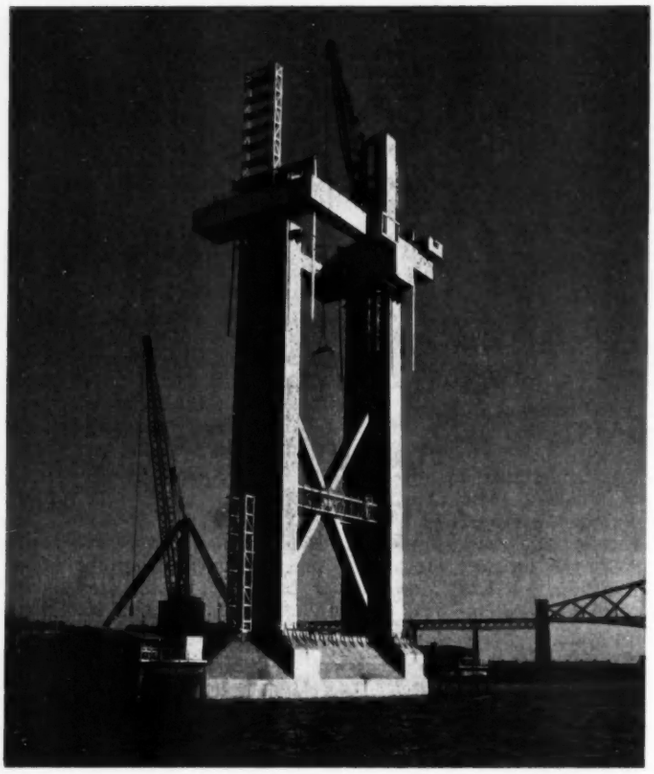
The elements forming the base of each tower are rather different from the upper ones, as can be seen from the drawing on the folding Plate, and are of mild steel plate

The anchorage face and chamber at one of the north anchorage tunnels. The prestressing cables are shown threaded through the tunnel concrete, their outer ends already fixed in zinc in their respective sockets. The sockets are held in groups of six by massive steel blocks; pairs of holes in these blocks, and the recesses behind them, will take the links which will carry the strand shoes of the suspension cable

Erecting the North Tower Steelwork

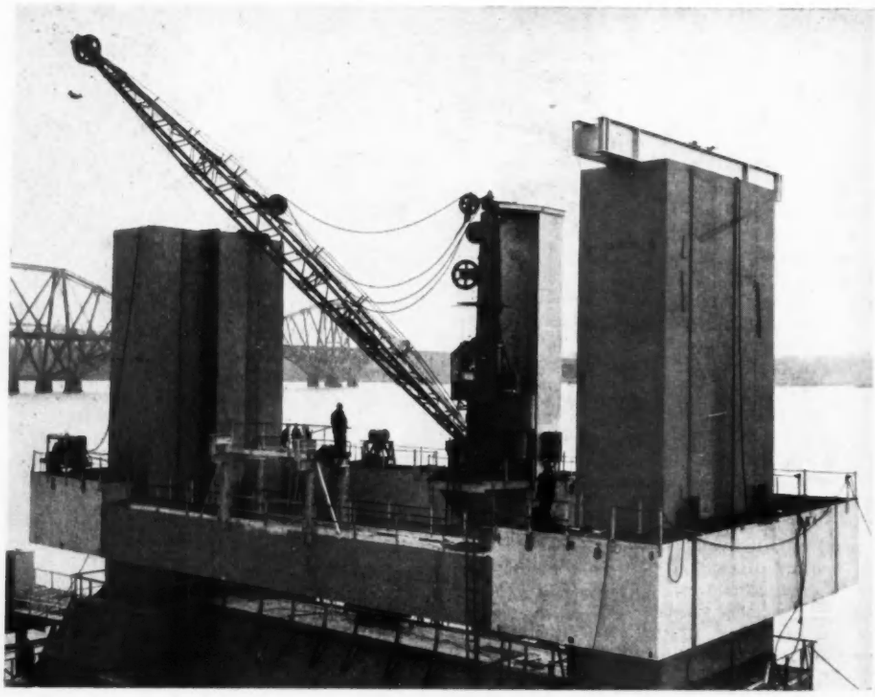
RIGHT : the North Tower as it was by the middle of December, with erection in progress. " Boxes " have been placed on the right-hand leg, but the cover plates are not yet in position, nor are the corresponding boxes on the left-hand leg. The tower-like cage on the left-hand side is part of the ring structure, comprising access gangways and ladders. The horizontal member of the tower which can be seen is the deck member ; reference to the folding Plate facing this page will identify the stage of erection reached ; a more recent view is shown in the heading illustration on page 296.



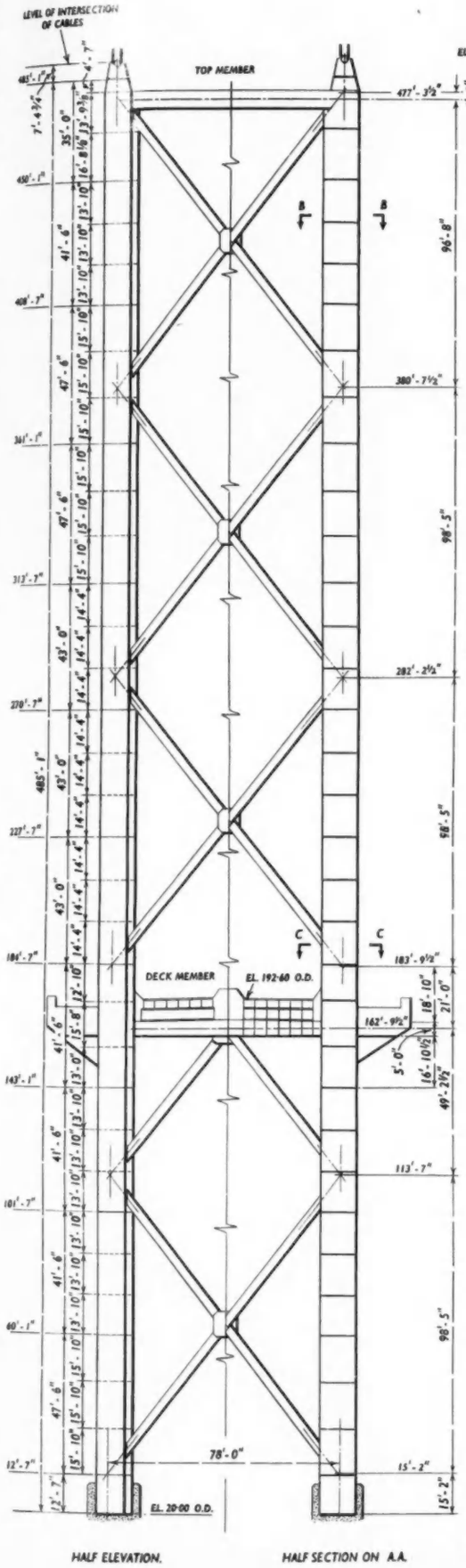


The illustration LEFT shows the tower less advanced, but is of interest because the ring girder is shown carried by its four links on the two cathead girders. The gangway used for bolting the bracings, and which follows below the ring structure, is shown being lifted. The first of the temporary hoist towers is being erected (both can be seen in the first illustration) and the door to the permanent lift inside the near leg can be seen.

Lastly, we show a closer view of the ring structure erected almost at ground level, as it was last September. The base section of the steelwork is concreted in, and just the first " lift " above it is in place. Note the shear plates on the outer boxes—below the collar plate only on the crane side but above and below it in the foreground—and the pair of support pins and collar plates.

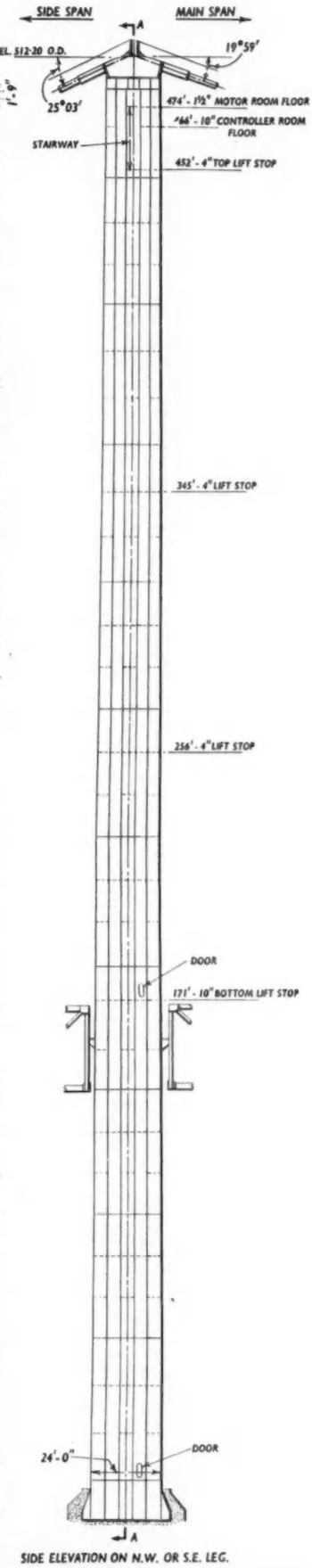


TOWER STEELWORK AND C



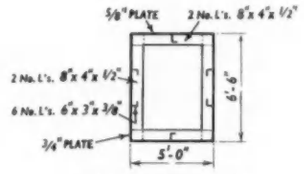
HALF ELEVATION.

HALF SECTION ON A.A.

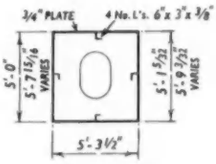


SIDE ELEVATION ON N.W. OR S.E. LEG.

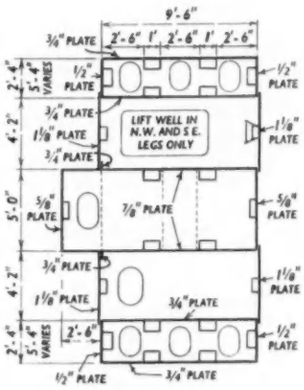
GENERAL ARRANGEMENT OF MAIN TOWERS.



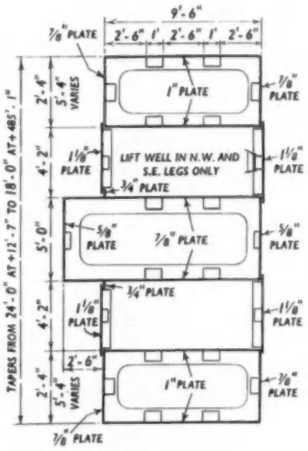
SECTION OF TOP MEMBER.



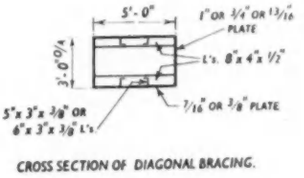
SECTION OF DECK MEMBER.



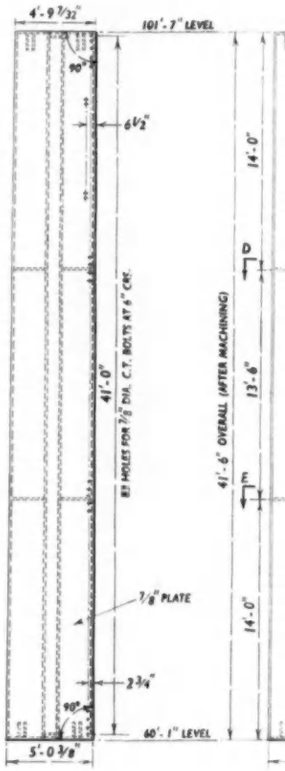
SECTION ON B.B.

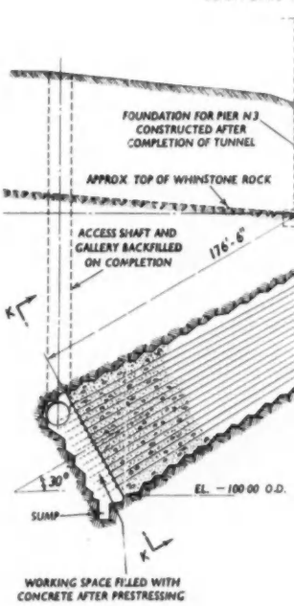


SECTION ON C.C.



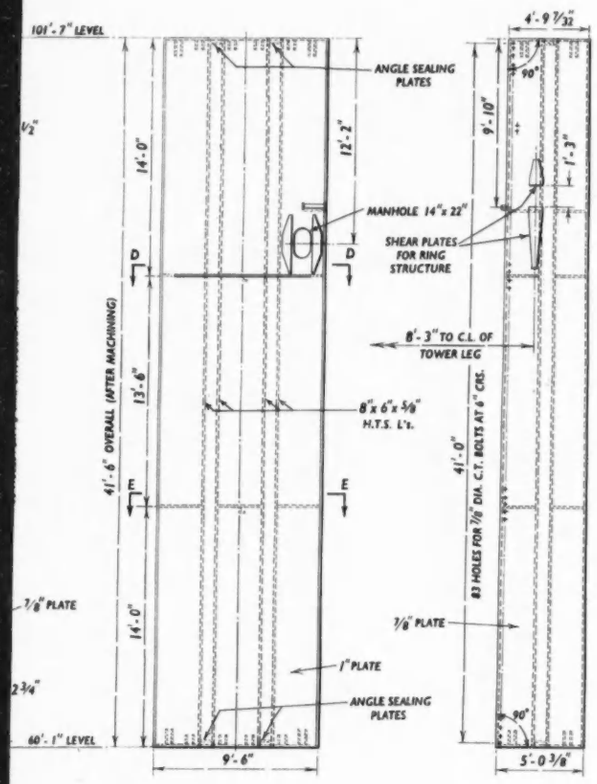
CROSS SECTION OF DIAGONAL BRACING.



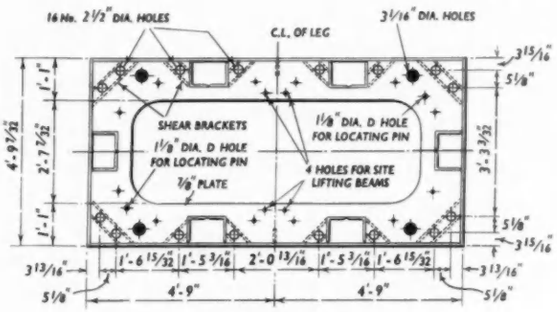


WORKING SPACE FILLED WITH CONCRETE AFTER PRESTRESSING

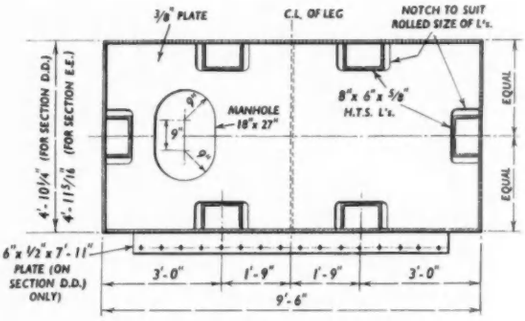
ND CABLE ANCHORAGES OF THE FORTH ROAD



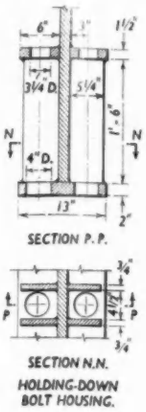
DETAIL OF TYPICAL PREFABRICATED OUTER BOX ELEMENT.

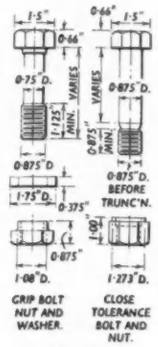


PLAN ON TOP PLATE.

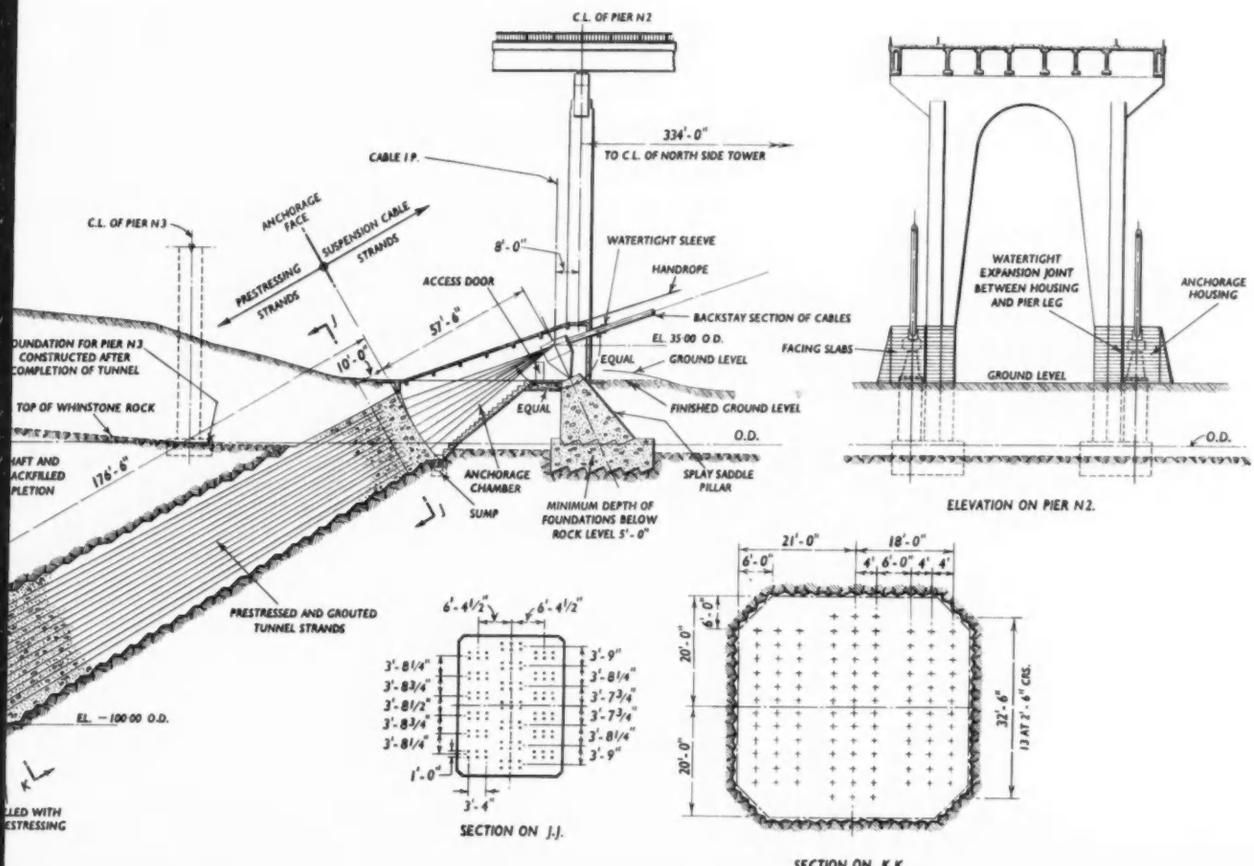


SECTION ON D.D. & E.E.





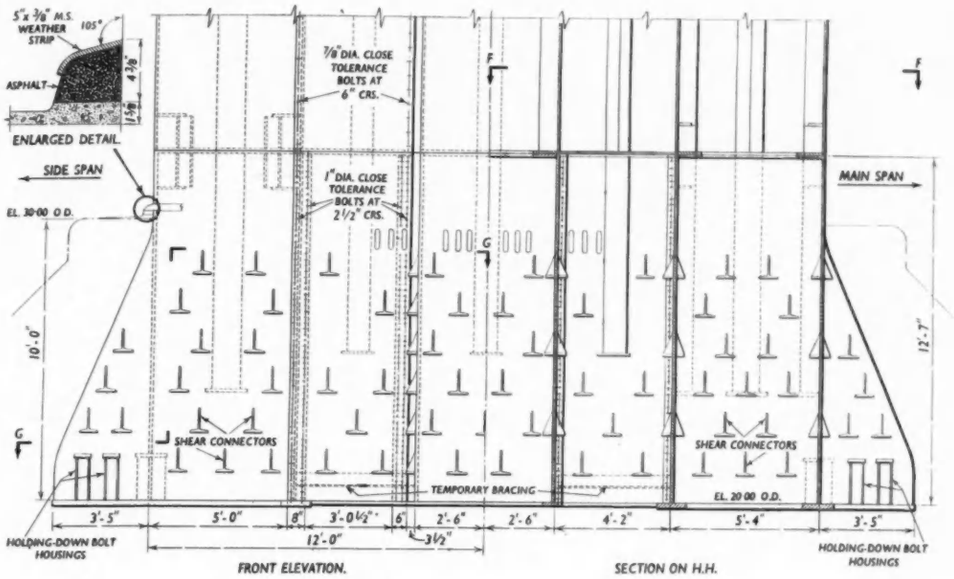
BOLT DETAILS.

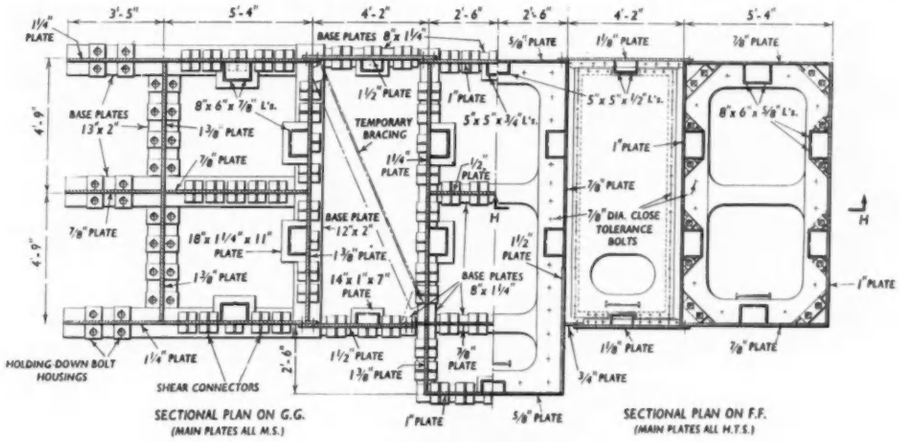


ELEVATION ON PIER N2.

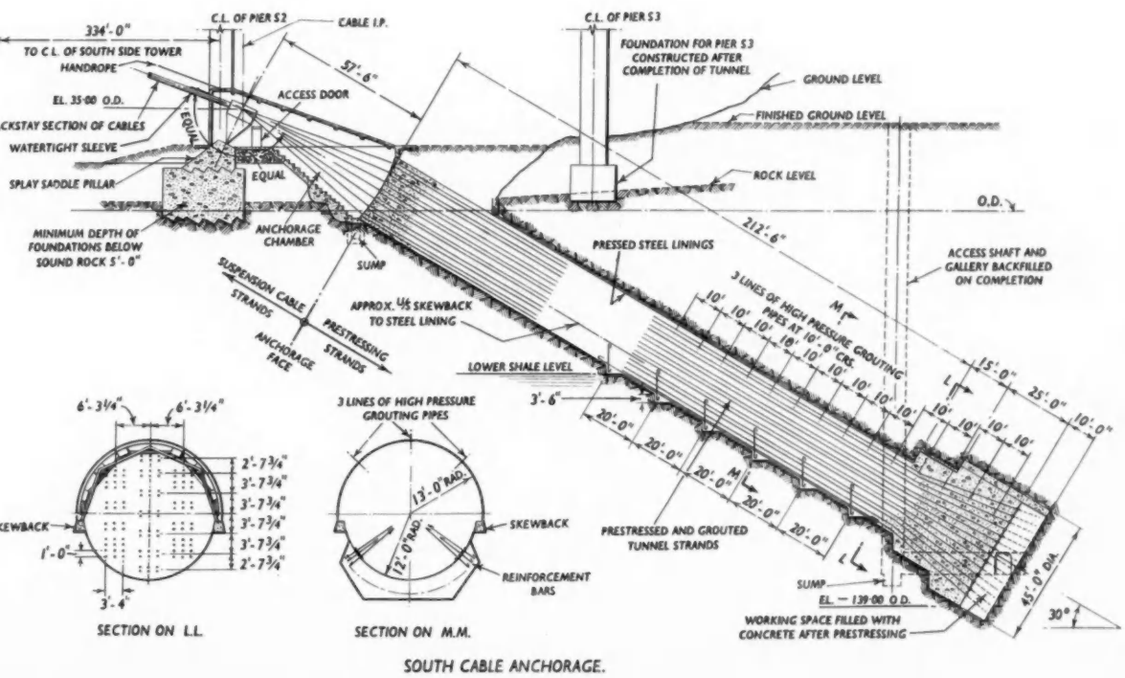
NORTH CABLE ANCHORAGE.

OAD BRIDGE





DETAIL AT BASE OF TOWER LEG.



SOUTH CABLE ANCHORAGE.

varying between 1½in and ½in in thickness, in contrast to the high-tensile steel used almost everywhere else in the tower. The height of this bottom "lift"—if such an expression is permissible!—of the steel is 12ft 7in, and after erection 10ft of this height was buried in concrete. Note the extra bearing area obtained from the large brackets built on to the two outer elements, and also from the numerous small shear brackets welded to all the surfaces.

This "lift" is held by 2¾in diameter high-tensile steel holding down bolts, of which there are fifty-six altogether. The bolts are 15ft long with 8in long threads, about 13ft of their length being anchored in the concrete.

The base was set on packings 6in clear of the concrete, and very accurately aligned and levelled. Then dry concrete was inserted under the base plates and rammed in. With this stage complete, the bolts were tightened, each bolt being tightened to 60 per cent of its yield stress, i.e. a load of 50 tons on a 2¾in bolt and a total preloading of 2800 tons on one leg of a tower. The concrete immediately below the base was heavily reinforced to withstand the stresses imposed by this operation, but its effect is, of course, counterbalanced by the addition of more weight as erection proceeds. The final stage of building the base consisted of placing the concrete around the base section, to give the pier its ultimate shape and finish.

A derrick of 35 tons capacity positions the lower sections of steel in the tower, and as erection proceeds, off-loads the steel on to upending bogies on a rail track built beside the pier. The steel is then upended and lifted off the bogies, raised and placed in position by the 32-ton crane on the ring structure. The illustrations on page 304 show the ring structure in use and give a good idea of its function. It is a welded-steel structure of box-shaped cross section, encompassing the two legs of the tower, bearing on them, and climbing up them as erection proceeds. It carries a 32-ton crane, hydraulic pumps and control gear in a cabin for operating the jacks for lifting itself; various ladders and platforms, protected by cages, to give access to the joints which have to be bolted; and various ancillary equipment. The pumps serving the hydraulic system are calibrated to give equal outputs, thereby ensuring that the jacks rise in unison and maintain the structure in a level plane.

Access to the ring structure is by two temporary hoists, one to each leg, which can also be used for small material. Bolting of the tower bracings takes place from latticed box girders which follow below the ring structure, the top and bottom chords of which are working platforms.

When the ring structure is in use erecting steelwork, it is held by four horizontal steel support pins each with a 1¼in thick collar plate on one end. These collar plates bear on 1¼in thick shear plates welded to the outer face of the outer boxes. On two of these boxes, those furthest from the crane, shear plates are also welded on above the collars to take uplift when the crane is operating. The ring structure is tied into the tower legs by rods to prevent the collar plates slipping off the shear plates when the unbraced legs attempted to deflect in high winds.

When a "lift" of steel has been completed, a cathead girder is placed across the top of each leg of the tower, and four links are suspended, one from each end of each girder. The ring structure is connected to these links by its jacking gear. With the links in use, the supporting pins and collars are withdrawn from the face of the leg, and the structure is then jacked up 1ft 6in at a time, to its next position; the support pins are moved forward, one lift higher, and the cathead girders are removed to allow erection to proceed.

The long arm of the ring structure on the side opposite the crane is, in fact, the permanent horizontal bracing member at the top of the tower, upon which two 10-ton cranes will eventually be mounted, for dismantling the climbing crane and ring structure, and for cable-spinning and related work. Provision of protected platforms and ladders on the ring structure is quite elaborate, and any plant required—a compressor for instance—can be lifted on to the main platform. Tensioned rope guides are also provided for use if necessary when the large box elements are lifted in high winds, to prevent them swaying and butting the tower.

When a steel element is lifted on to the tower, it is first "located" by two fitted dowels, which ensure that the element is accurately in position. The large high-tensile bolts shown at the corners and along the edges of the joint—these are the "holding down" bolts—are then inserted and tightened. These bolts are 2½in to 1½in in diameter and provide the main strength of the joint. They are tightened manually with a flogging spanner and will be retightened several times as more deadweight is added to the towers with consequent loosening of the bolts. The smaller bolts spaced around the periphery of the joint, which are grip bolts, are then inserted and tightened with an impact wrench. These bolts also are taken one turn beyond tightness, which gives a preloading in excess of the yield point of the steel of the bolt. The narrow shank of these bolts ensures that yield occurs in the shank. The collar on the nut helps to distribute the load more evenly amongst the threads. Thus the bolt is in tension, not in shear, and the joint is held by friction between the meeting faces.

A complete explanation of the various duties needed at a joint between adjacent "lifts" of boxes can be gained by reference to the plan on the top plate of the typical box drawn in the inset plate. The four 3 1/16in diameter holes drawn as heavy black circles are for handling the box; the two holes for the locating dowels or pins are shown; four holes for the cathead girder (called "site lifting beam" on the drawing) are shown; then there are sixteen 2½in diameter holes for the holding down bolts; and the remaining holes are for the grip bolts. A detail shows a grip bolt, nut and washer and a close tolerance bolt, but the detail of the holding down bolt housing relates specifically to the base section of the tower drawn on the right.

The critical condition which the bolted joints have to withstand is that of a gale blowing on the free-standing tower, i.e. before the construction of the suspended structure. The vertical load of the latter is sufficient to make bolting unnecessary when the bridge is complete. For the free-standing condition, the joints are designed to be on the point of opening under a gale of 110 m.p.h. More strictly, the wind speed is taken as 110 m.p.h. at a point about a third of the way up the tower, with a velocity distribution such that it is fiercer above, and slightly less below this point.

The function of the 2½in to 1½in diameter bolts is to resist the tension due to the bending moment imposed by the wind. Thus a substantial pretension is imparted by these bolts concentrated at the outer corners and edges (they are held by substantial brackets) corresponding to the tension at the joint when a 110 m.p.h. wind is blowing. These bolts are, as their name implies, analogous to the holding down bolts at the base of the tower, though they "hold down" steel with respect to steel, rather than holding the steel structure on to the concrete. The function of the "grip" bolts is to resist the shear forces in the tower, which necessarily accompany bending loads when a wind is blowing. In this case a uniform frictional load spread across fairly thin end flanges is called for, and hence small-diameter bolts spaced quite closely round the diaphragms are required.

"Grip" bolts are again used to fasten the cross bracings to the larger central box of each tower leg, but close tolerance bolts connect the cover plates to the boxes.

The steelwork is largely treated on the site to protect it from corrosion. Plant has been installed in a hangar on the south shore at Drem, where new machines, which are prototypes of their kind, have been installed. Protection consists of (*a*) shot blasting, (*b*) metalising with one coat of zinc and (*c*) painting with four coats—an etch primer, followed by a zinc chromate-in-phenolic coat, and lastly by two micaceous-iron-oxide-in-phenolic coats.

The Institute of Metals

THE 1961 Spring Meeting of the Institute of Metals will be held in Church House, Westminster, from March 21 to March 23, the proceedings commencing with the Annual General Meeting.

Following the consideration of the Report of Council and other such routine business, the retiring President, Sir Ronald Prain, O.B.E., Hon. M.I.M.M., is to install Professor H. O'Neill, M.Met., D.Sc., F.I.M., as the new President. Professor O'Neill will then read his Presidential Address, and the Institute of Metals (Platinum) Medal, The Rosenhain Medal, and the W. H. A. Robertson Medal and Premium are to be presented.

Five concurrent scientific sessions and three evening functions have been planned as follows:

Scientific Sessions

Date	Session A	Session B
Tuesday, March 21 2.30 p.m.	Compatibility Problems in Gas-Cooled Reactors	Aluminium Alloys (Four papers)
Wednesday, March 22 10 a.m.	Copper Alloys (Four papers)	The Contribution of Constitutional Research to General Metallurgical Problems
2.30 p.m.	X-Ray Fluorescence Analysis	(As above, continued)
Thursday, March 23 10 a.m. and 2.30 p.m.	Extrusion	Discussion, to be arranged by the Metal Physics Committee

Evening Functions

Tuesday, March 21 6.30 p.m.	The May Lecture, by Professor M. Polanyi, D.Sc., F.R.S., at the Royal Institution, Albemarle Street, London, W.1.
Wednesday, March 22 7.30 p.m. to 10.30 p.m.	Conversazione and Exhibition, 17, Belgrave Square, London, S.W.1.
Thursday, March 23 7.0 p.m. for 7.30 p.m.	Annual Dinner and Dance, Grosvenor House, Park Lane, London, W.1.

In recognition of the services they have rendered to the Institute of Metals over many years, the Council has elected Major C. J. P. Ball, D.S.O., M.C., F.R.Ae.S.; Dr. Maurice Cook, Hon. A.C.T. (Birm.), F.I.M.; and Lietenant-Colonel S. C. Guillan, T.D., as Fellows of the Institute; a much appreciated honour as the total number of Fellows is restricted to twelve. They have also elected as an Honorary Member Professor William Hume-Rothery, O.B.E., Ph.D., M.A., D.Sc., F.R.S., the Isaac Wolfson Professor of Metallurgy in the University of Oxford.

SHORTER REPORTS

Naval Architects Spring Meeting

THE Spring Meeting of The Royal Institution of Naval Architects will be held in the Weir Lecture Hall, 10, Upper Belgrave Street, London, S.W.1, on March 28, 29 and 30. On the morning of Tuesday there will be held the annual general meeting followed by a paper entitled "International Conference on Safety of Life at Sea, 1960, Convention," by R. J. Shepheard. In the evening the annual dinner will be held at Grosvenor House. Four papers, two in the morning and two in the afternoon, will be presented on Wednesday, namely: "Hull Structural Steel—The Unification of the Requirements of Seven Classification Societies," by G. M. Boyd and T. W. Bushell, A.Eng.; "The Behaviour of Long Deckhouses," by J. C. Chapman, Ph.D.; "Scale Effect Experiments on 'Victory' Ships and Models," Parts III and IV, by Dr. Ir. J. D. Van Manen and A. J. W. Lap; and "The Effect of Section Shape on Ship Behaviour in Waves," by G. Vossers and W. A. Swaan. A further four papers will be read on Thursday, March 30, when T. R. F. Nonweiler, B.Sc., will give "Stability and Control of Deeply Submerged Submarines" and "The Propulsive Performance of a Group of Intermediate Tankers" will be presented by H. J. S. Canham and W. M. Lynn. The meeting will conclude with the presentation of "Tank Boundary Effects on Model Resistance," by G. Hughes, D.Sc., Ph.D., and "B.S.R.A. Methodical Series Experiments—An Overall Presentation," by D. I. Moor, B.Sc., M. N. Parker, B.Eng., and R. N. M. Pattullo.

Analogue Computer Symposium

ON April 10 and 11 a symposium on the applications of analogue computers will be held at the Loughborough College of Technology, Loughborough, Leicestershire. Beginning at 11 a.m. on April 10, the first day will be devoted to introductory lectures on analogue computing techniques. On the second day specialists from industry and computer manufacturers will discuss applications of computers in various industries, and future trends. Applications may be made for attendance on either or both days. Overnight accommodation is available on the nights of Sunday, April 9, and Monday, April 10. The symposium is being organised by the Departments of Electrical, Mechanical, Aeronautical and Chemical Engineering at the College.

Nuclear Reactor Pressure Vessel Passes Test

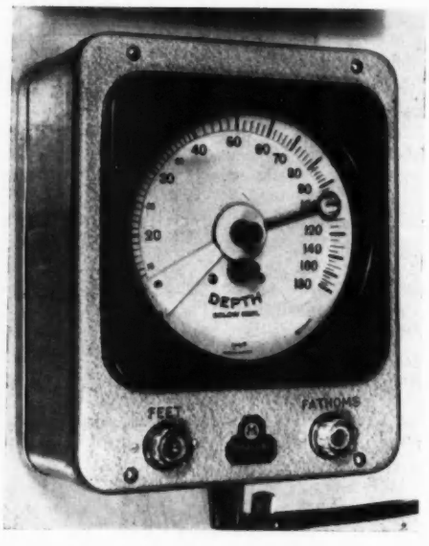
THE No. 1 reactor pressure vessel at the atomic power station at Hinkley Point, Somerset, was successfully pressure-tested last week-end at the highest pressure so far produced in vessels of this kind. The operation was carried out without a hitch and was completed six hours ahead of schedule. The pressure vessel, a 67ft diameter sphere built by Babcock and Wilcox, Ltd., from 3in thick mild steel plate, is believed to be the largest ever to have been tested on site and it successfully withstood a pressure of 310 lb per square inch, over one-and-a-half times the pressure it will have to stand in service. Over 3,750,000 cubic feet of free air was pumped into the vessel to achieve this pressure. The sphere was pressurised in stages, the highest pressure being reached during the early hours of Sunday afternoon. Special driers were used to remove the moisture from the air before it was pumped into the vessel, and the temperature of the sphere was also raised to 86 deg. Fah. to ensure that the inside was perfectly dry. The vessel will now be subjected to a vacuum test. Over 20 miles of special cored wire were used to connect up the 274 strain gauges and the thermocouples that were fixed inside and outside the vessel to record stresses and temperatures.

To ensure complete safety of personnel the tests were conducted at the week-end when the site was free of the 1500 workmen and administrative staff. The forty or so technicians supervising the operations were housed in temporary accommodation in the adjacent second reactor building. The Hinkley Point atomic power station, which is being built for the Central Electricity Generating Board by English Electric, Babcock and Wilcox, Taylor Woodrow Atomic Power Group, will generate 500,000W, and the first reactor is expected to go into service next year.

Meter Display of Echo Soundings

AN echo-sounding equipment known as the "Metron," in which the depth of water beneath the ship is indicated by a pointer on a graduated circular scale, is announced by the Marconi International Marine Communication Company, Ltd., Chelmsford. The frequency of "Metron" soundings is approximately one per second, and the readings show the actual depth at each sounding—not an average of several soundings.

The scale covers 14ft to 180ft and 14 fathoms to 180 fathoms, and a neon-light indication is given of the units selected, as seen in the illustration. A cursor, adjustable by means of a knob in the centre of the dial, can be set at the last significant reading for the purpose of checking any appreciable changes in depth, or preset on a given



Scale and pointer depth presentation in echo sounding equipment

mark so that the moving pointer will show when it is reached..

A complete "Metron" installation consists of the display meter itself, an amplifier integrator, the transceiver, a control switch, and the projector assembly. Operation may be direct from 115V, 50–60 c/s, a.c. mains or through a rotary converter from d.c. mains of 110V or 220V.

The amplifier integrator uses a computer technique to derive from the signal received back from the seabed at each sounding a voltage analogue which is applied to the display meter. All other echoes received are automatically rejected by the integrating characteristics of the amplifier. The transceiver employed is that designed for use with the high-power "Seagraph III" recording echometer, and it is expected that much of the demand for the "Metron" will be for installation with the "Seagraph III" in order to take advantage of using a single transceiver to provide either recorded or instantaneous meter information.

[Reply Card No. E3064]

Electric Dishwasher

A DISHWASHER designed for the domestic market, and capable of operation wherever a supply of hot water and an electric point are available, is being introduced by Electrolux, Ltd., 153/5, Regent Street, London, W.1. The Electrolux "Dishmaid," of which a sectional view is reproduced, measures 21⅝in high by 21 ⅞in in

Sectional view of dishwasher showing motor (at top), pump and directions of jet sprays

diameter and weighs 40 lb unloaded. It will stand on a draining board (direct or by means of a metal stand which leaves parking space for crockery underneath), or can be mounted on a wall bracket. Its compact form, low weight and independence of permanent connection with water and electricity supplies give freedom of positioning in the kitchen and a measure of portability—enabling it to be taken on holiday and used on a caravan site, for example, if mains electricity is laid on. Crockery, cutlery and glasses to be washed are loaded into a circular rack which is rotated by a silent-running 75W split-phase motor. Through the same shaft the motor drives a centrifugal pump running in water-lubricated carbon bearings, while a water distributor operated through nylon bevel gears diverts the pump output in turn to the five jet pipes which direct sprays on to the contents of the machine as they rotate. The basket is driven at 6 r.p.m., and the timing of the delivery to the jets is such that at each revolution the contents are sprayed from five different directions. The initial operation is a through rinse with the water outlet from the machine open so that refuse is carried away into the sink. After a minute the outlet may be closed and the sump of the machine filled with fresh water. The sump has a capacity of seven pints, and when this is exceeded water appears at the overflow, indicating that the tap may be turned off. Washing then continues for at least four minutes, but may be prolonged as convenient with the machine unattended.

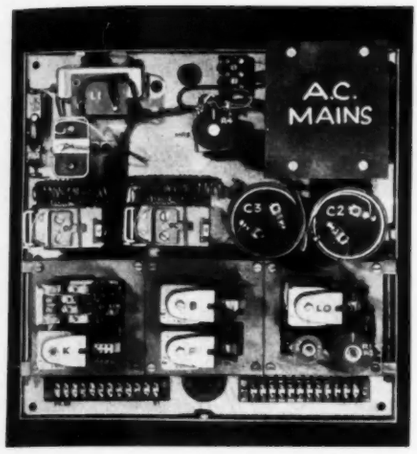
A slipping clutch in the drive prevents damage to the motor if rotation of the basket is impeded, and the retention of water in the sump avoids running the machine dry or risk of flooding the kitchen by accidental disconnection of the hose, since throughout the unattended wash the water tap is off. A final through rinse with the outlet open as before completes the washing.

[Reply Card No. E3065]

Internal Telephone System

A SMALL internal telephone system providing for ten lines is announced by the Private Telephone Department, A.E.I. Telecommunications Division, Siemens House, No. 3 Avon Trading Estate, West Kensington, London, W.14. The automatic switchboard of this equipment, PAX 61, measures only 10½in by 10½in by 6in. Ordinary dial telephone instruments are used and can be located up to 3 miles away if 23 s.w.g. wire is used, or 6 miles with 20 s.w.g. When expansion demands a larger exchange, the telephones and wiring already installed for the PAX 61 can be incorporated in the new system.

The equipment operates from any a.c. mains supply, having its own power unit to provide 50V d.c. for operating the system. Single-digit



Interior of automatic ten-line exchange, showing plug-in miniature uniselectors to the left of the two condensers C2, C3 in centre of panel

dialling from 0 to 9 caters for every extension. Dialling tone is provided. A " priority " button can be fitted to selected telephone instruments to override the ringing tone of a call dialled from another instrument. This facility requires one extra wire to the instrument.

The compactness of the PAX 61 switchboard is derived largely from incorporation of the miniature uniselector developed by A.E.I. for the British Post Office. This plug-in uniselector occupies no more space than the conventional standard Post Office 3000 relay, and has an economic life of some 8,000,000 operations. No soldered connections have to be broken when replacement is necessary. Either the new British Post Office telephone, in a variety of colours, or the A.E.I. " Centenary Neophone," in twenty-one colour combinations (matching and two-tone), is supplied with the PAX 61.

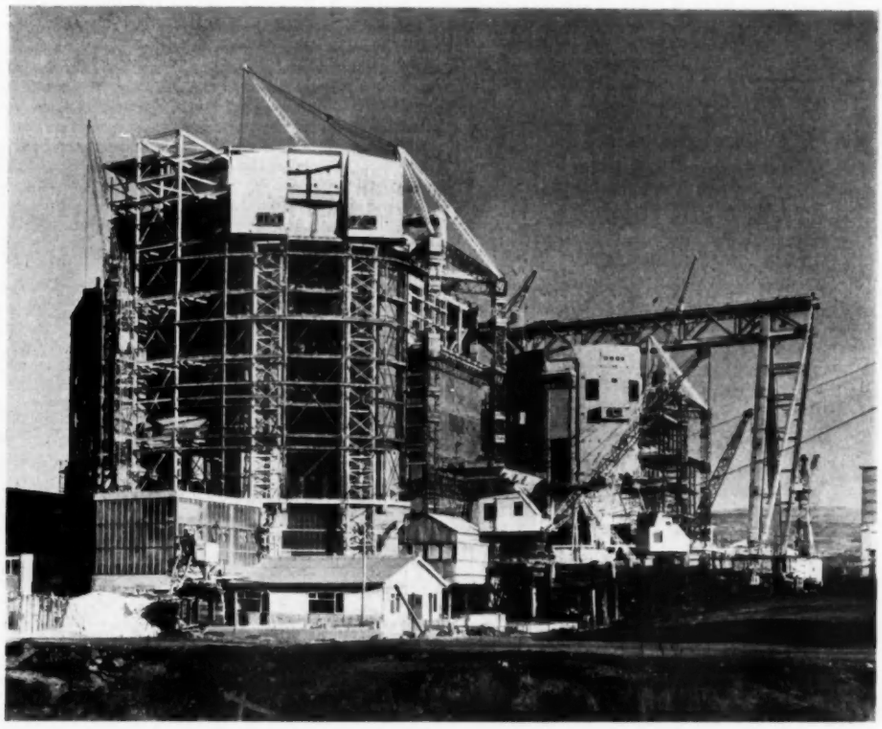
[Reply Card No. E3071]

Progress at Hunterston Nuclear Power Station

THE shells of five of the steam-raising-units associated with the first reactor at Hunterston nuclear power station have now been placed on their plinths. This 300MW station is being built on the Ayrshire coast for the South of Scotland Electricity Board by the G.E.C. and Simon-Carves Atomic Energy Group.

With these shells in position a start has been made on the installation of the gas circulators and the tubing inside two of the steam-raising units. To do this a " clean conditions " building has been erected on top of each shell. Some parts of the gas circulators will be installed from below the steam-raising units.

As can be seen from the illustration much of the structural steelwork in the vicinity of four of these units has been erected, enabling the h.p. and l.p. steam drums and associated pipework to be mounted in position. Long before this the face of the reactor should be ready for glazing ; on the adjoining exit building glazing is practically complete.



Hunterston nuclear power station. The shells of five steam-raising units for reactor A are in position and plant and tubing are being installed inside two of them. This picture shows the associated " clean conditions " building and structural steelwork, with reactor B and the Goliath crane in the background

The hot and cold gas ducting, together with the main valves and expansion bellows units which link the pressure vessel of reactor " A " with the steam-raising units is being connected up. Stress-relieving of the welds involved will be carried out *in situ*.

Reactor " A " pressure vessel is being prepared for stress-relief, and about a quarter of the bottom head has been externally lagged with 6in thick thermal insulation. Thermocouple points for temperature measurement have already been prepared and a structure for carrying the electric heating elements is being erected. All the control-rod nozzles of this vessel have been welded and are being inspected. About half of the stand-pipes which will be fitted to these nozzles are on site, but none will be installed until after the pressure vessel has been stress-relieved. When the reactors are in operation the top inner surface of each vessel is to be cooled by diverting some of the carbon-dioxide coolant gas through a system of pipes, perforated on their upper surfaces, and suspended from the inside of the top head. These pipes have now been erected inside the first reactor pressure vessel.

It will be recalled that a service machine and crane will be mounted above the top concrete biological shield of each reactor. Now the civil engineering work of the first reactor is sufficiently advanced for erection of the crane and service-machine structure to be started. Testing of the control-rod recovery and handling mechanisms inside the first service machine is in hand at the Erith Works of G.E.C.

Inside reactor " B " the main activity is connected with the fabrication of the pressure vessel. Last month the 340-ton support grid was lifted into position to be followed shortly by course No. 3 of the vessel itself.

Good progress is also being made on the construction of the maintenance building for the charge machine which will operate below the reactors. With most of the exterior work complete, attention is being paid to the installation of the services including ventilation ducting, lighting and heating. A traverser to assist in the replacement of a charge-machine by its spare is to be located in a pit inside the building. Parts of the traverser are already there being painted before erection.

Foundation steelwork of four of the six 60MW turbo-generators is being erected in the turbine hall, that for sets Nos. 1 and 2 being well advanced, permitting a start to be made on the erection of the first set. Installation of the condenser for No. 1 turbo-generator is finished and a pressure test has been successfully carried out. The first turbine was tested at Erith towards the end of last year and the second is in course of preparation.

The main walls of the cooling pond for the fuel element cartridges having been cast, work is beginning on the construction of the internal pond walls. At the same time construction of the east and west blockhouses through which irradiated fuel elements will pass on their way to the pond is going ahead.

All six of the circulating-water pumps and their 800 h.p. driving motors have now been installed and aligned in the pump-house situated near the intake works, about ¼ mile from the reactors. Next to this pump-house is a room which will ultimately contain the automatic dosing gear and pumps for delivering chlorine solution to the intake headworks to prevent fouling of the culverts and pipes by marine organisms. Much of this equipment is already installed.

The scheduled time for criticality of reactor " A " is August, 1962, and of reactor " B ", May, 1963.

Institution of Agricultural Engineers

THE annual general meeting of the Institution of Agricultural Engineers is to be held at the Piccadilly Hotel, London, W.1, on Tuesday, April 25. This year, for the first time, the Institution is combining with the A.G.M. a one-day conference and dinner. The conference will open at 11.30 a.m. with a paper by Mr. C. H. Hull of David Brown Tractors, Ltd., entitled " Tractor Requirements for International Agricultural Engineering Standards." At 2.30 p.m. the speakers will be Mr. J. Gass of Ransomes, Sims and Jeffries, Ltd., Mr. G. P. Harding of G. P. Harding and Son, Ltd., and Mr. J. C. Hawkins of the National Institute of Agricultural Engineering, and the subject " Why Plough ? " This will be followed at 4.15 p.m. by a paper " Technological Considerations of the Uses of Metals in Agricultural Engineering," given by Mr. I. G. Slater of the College of Technology, Birmingham. Mr. W. D. Akester, president of the Agricultural Engineers Association, will be the principal speaker at the dinner.

SHORTER REPORTS *(Continued)*

Slag Processing at Margam

BLAST-FURNACE slag has long been used as a road material, as railway ballast, and for several other purposes, but its processing in large quantities under scientific control is of more recent date. The recently-completed slag plant operated by the Margam Slag Company, Ltd., Morfa Bank, Abbey Works, Port Talbot, Glamorganshire, exemplifies the extent of modern slag processing.

The plant takes its slag from the five blast-furnaces of the Steel Company of Wales, Ltd., nearby, which produce some 16,500 tons of this material each week. Close control is exercised over the slag composition by the blast-furnace management—this is necessary in any case for the consistent production of high-grade iron—and only slag of approved quality is sent to the Morfa Bank plant for processing. It travels in rail ladles of 20 tons capacity each, and since the cooling of the slag is important if a hard, dense material is to be produced, it is tipped on specially prepared banks of 60,000 tons total capacity. When cooled, the slag is dug out by Ruston-Bucyrus 54RB and 43RB excavators and loaded into A.E.C. 12-ton tipping vehicles for the short haul to the processing plant receiving hopper, which is of 25 tons capacity.

From the hopper the " as-dug " slag passes under electro-magnets, which remove any tramp iron present. Crushing follows, in three stages, the crushers and crushing layout being designed to produce the most suitable particle shape for roadstone, railway ballast, filter media and concrete aggregate. The primary crusher is a 42in by 25in Kue Ken jaw crusher, the secondary a Symons 3ft cone machine and the tertiary a Symons 4ft short head cone crusher. This crushing equipment allows the entire output of 110 tons per hour to be reduced to $-\frac{3}{4}$in, if required, of which 90 tons per hour will be $-\frac{1}{2}$in.

The product from the crushers is fed to a Symons double deck selector screen which divides the feed into four sizes ; the largest is returned to the secondary crusher, while the smallest can be passed direct to the sizing screens or alternatively, through a rotary drier if necessary. The two remaining sizes can be passed direct to the sizing screens or returned to the tertiary crusher for further reduction, according to customers' demand for different sizes. Material from 6in to 2in can be taken off at this point in the plant if required.

Four Symons 4ft by 14ft screens next separate the material into ten sizes, the upper and lower limits of which are $-2\frac{1}{4}$in $+1\frac{1}{2}$in, and $-\frac{1}{8}$in. These ten products are stored in separate bins, each of 120 tons capacity, and any one can be drawn off into road vehicles as required. Beneath the storage bins are ten automatic proportioners, which can be used to batch the material as required, to an accuracy of $\pm\frac{3}{4}$ per cent.

Crushed and graded slag which is to be coated for road work passes to the coating section of the plant, which has two heating and mixing machines, each of 60 cubic feet capacity, arranged side by side. Graded batches of material from the storage bins are delivered into one of two weigh hoppers, which checkweigh the complete batch. The material is then pre-heated to the correct temperature and passed to the paddle mixer where the selected binder is added. Filler and flux oil can also be added at this stage if required. The mixed batch can be discharged direct into motor lorries or into one of six mixed material hoppers, each of which holds 18 tons. Three types of binder are stored in Clarmac heaters, with thermostatic temperature control.

The control of mixing is fully automatic, from a Dewhurst panel with plug-in preset circuit boards for the various mixes. The installation is fully capable of supplying all the requirements of three mechanical finishers, that is, 200 tons to 300 tons a day, as well as meeting the demands of a number of hand laying gangs.

The complete project has been designed and erected in less than a year. Site preparation was carried out by the civil engineering department of the Steel Company of Wales, and the design and manufacture of the mechanical plant were contracted to Stothert and Pitt, Ltd. The foundations and buildings were designed and constructed by George Wimpey and Co., Ltd., and the Mechanical and Electrical Division of the same company was responsible for the electrical installations.

Monitor screens and closed circuit TV camera control rack (left) in car body inspection control room

Television Control of Car Body Inspection

THIRTEEN closed circuit television camera channels and associated equipment have been supplied by Marconi's Wireless Telegraph Company, Ltd., Chelmsford, as part of an automatic routing system to facilitate the inspection of new car bodies at the Standard-Triumph Motor Company's Works, Coventry. Cars arrive on conveyor belts from the manufacturing areas into a new extension hall for further inspection. Each model is carried in a skip which incorporates trip devices peculiar to the model it is intended to carry. The trips actuate routing mechanisms on the conveyor belt system to channel the vehicles automatically to their correct destinations in the area. Here they undergo a series of stringent inspections after which the " passes " are automatically delivered to other floors while any rejects are diverted along a rectification line for further work to be done on them.

The closed circuit television installation fulfils several functions in the routing and inspection processes. Cameras installed at strategic points within the area feed 14in Marconi monitors in a central control room. Five cameras in various parts of the body storage area enable controllers to identify the car bodies passing along the conveyor belts so as to keep the Programming Department informed of the current position. Details of colour and relevant data are carried in code form on a card on each vehicle.

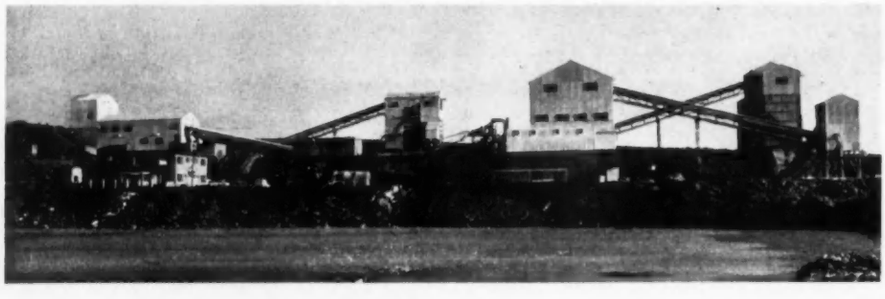
Any of the remaining eight cameras can be switched to the sixth picture monitor, so that a controller can keep watch on the passage of vehicles at all stages of progress. The use of television thus enables all supervision to be carried out from a central point and removes the necessity for a man to be stationed at every point equipped with an open telephone line to the Programming Department. The Marconi installation consists of thirteen BD871 camera channels and eight BD879 picture monitors, together with ancillary equipment. The thirteen control units which form part of the camera channels are contained in a single rack-mounting unit with an oscilloscope for monitoring purposes, as seen in the accompanying illustration of the control room.

[Reply Card No. E3082]

Two Production Machines

PARTICULARS have been received from Crossley Brothers, Ltd., Openshaw, Manchester, of two production machines of new design the firm is now manufacturing. One of these machines is designed for the high-speed production of threads on wood screws by a hammering process ; it was developed by Mr. Walter Trurnit and the British firm has acquired the world manufacturing and selling rights. The second machine, a double ended taper turning lathe invented by Mr. Wilhelm Beer of Wiesbaden, is being manufactured by Crossley Brothers, Ltd., for sale in the British Commonwealth and the United States.

The Crossley-Beer lathe, shown at the foot of page 309, is arranged for the turning of identical tapers in the bore of a valve body and on the mating plug of taper valve cocks, as well as for the manufacture of other types of mating conical components. It swings workpieces up to 12·59in between 19·68in centres. The centrally mounted headstock has two independent co-axial spindles, each driven through vee belts and gears by a 5- 6 h.p. motor and having eighteen speeds from 235 to 3000 r.p.m. on the standard



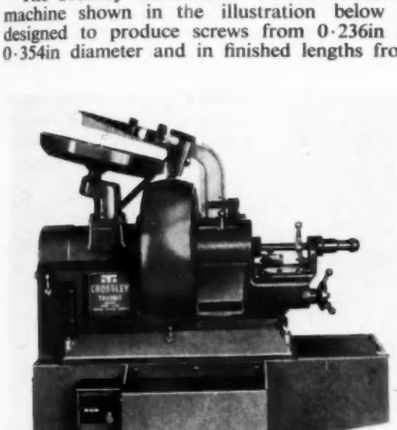
Margam slag plant produces all types of dry and coated blast-furnace slag

machine, alternative speed ranges being available to special requirements. This headstock can be swivelled up to 15 deg. so that the same taper is machined on workpieces carried in holders mounted on the co-axial spindles on each side.

Extensions to the bed on each side of the headstock have precision slideways on which carriages are longitudinally traversed by independent motor drives. These carriages have thirteen roughing and thirteen finishing feeds ranging from 0·0002in to 0·0468in per revolution of the spindle, with a quick traverse rate of 86in per minute. The tool post of one carriage carries the roughing and finishing boring tools for machining the taper bore and the other carriage is provided with turning tools for the taper plug. On the side used for plug turning a tailstock is supported from an overhead horizontal beam carried on and swivelling with the headstock.

The operating sequence on each side of the machine is independent so that whilst one component is being turned or bored that on the other side can be changed. The machining operations are under automatic sequence control preselected by contact plugs on the control panel on the machine.

The Crossley-Trurnit screw thread hammering machine shown in the illustration below is designed to produce screws from 0·236in to 0·354in diameter and in finished lengths from



Machine for producing the threads on wood screws by a high-speed hammering process

2·36in to 5·12in. In this machine the threads are cold formed by a hammering process whereby the slowly rotated blank is hammered by rotating dies which are operated radially inwards. A hollow cam wheel encircles the dies and through them imparts some 6000 blows a minute on the blank during the thread forming operation. The blanks are prepared for hammer thread forming in a separate pointing machine which turns a point or cone and cuts the leading two or three threads on the tip of a blank. When the initially machined blanks are fed into the thread hammering machine the threads on the tip are picked up and extended along the required length of the screw. Both of the machines are arranged for hopper feed and two pointing machines can serve three hammering machines.

It is claimed that the hammering process is more rapid than conventional thread cutting processes and substantial savings in material are effected as a screw blank is elongated by 15 to 20 per cent as the threads are formed. Hammer forming of the threads gives a good bright finish to the screws with favourable grain flow along the material. Screws produced by this method are stated to be some 20 per cent stronger than those with cut threads. The tooling can quickly and easily be changed for different screw sizes and the dies have a longer effective life than thread cutting tools.

[Reply Card No. E3083]

Floating oil boom at a cut-out berth at Ellesmere Port

Inflatable Oil Boom

To limit the possible area of water pollution due to accidental spillage when oil and petroleum products are transferred from ship to shore it is possible to install a floating boom. Such an inflatable oil boom, which is approximately 650ft long, encloses a cut-out berth at Ellesmere Port in the Manchester ship canal, and can be seen in position in our illustration. Associated with the boom is an air pressure installation which inflates the boom initially and again after the air has been released to sink the boom to allow vessels to enter and leave the berth. The device consists of a flexible, inflatable tube made of neoprene synthetic rubber and reinforced with "Terylene" synthetic fibre. A weighted skirt of the same material hangs below the tube to a depth of 22in and so prevents seepage underneath the tube. A chain weights the skirt and helps to prevent the tube and skirt from taking any tensile stresses due to wind, waves or currents.

The minimum diameter of the tube able to withstand the buffeting of the sea and also support skirt and chain is considered to be 16in. Any number of sections of tube, which is made in lengths of 50ft, can be jointed together to achieve the required overall length. The air pressure required is about 2 lb per square inch and since excessive pressure would make the boom too rigid to respond quickly to changing wave profiles there is a safety valve set at 4 lb per square inch.

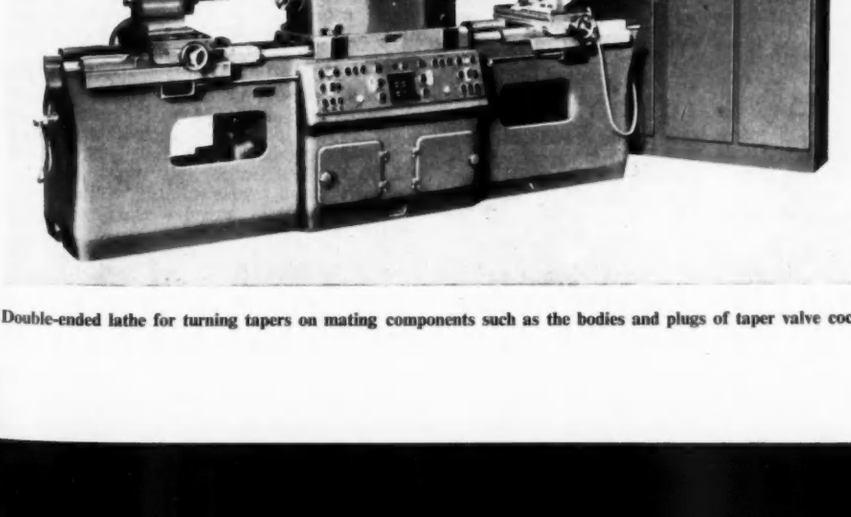
Neoprene is highly resistant to petroleum products, sea-water, abrasion and weathering and will not support combustion. As an example of the toughness of the material it is recorded that when some 600 tons of burning crude oil fell into the area enclosed by a boom, the oil burned for an hour but the boom remained inflated and prevented the burning oil from becoming a serious hazard to other shipping and shore installations. William Warne and Co., Ltd., design and manufacture the floating oil booms and the raw neoprene is provided by the Du Pont Company (United Kingdom), Ltd.

[Reply Card No. E3091]

Largest Power Station can be Built at West Burton

THE Central Electricity Generating Board has now received the consent of the Minister of Power to the establishment of the first of the two large coalfired power stations that it proposes should be built in Nottinghamshire to burn coal from the East Midlands coalfield. The station now approved will be situated at West Burton about 2 miles south-west of Gainsborough and will be the most powerful steam station in Western Europe. The generating plant will consist of four turbo-generators each with an installed capacity of 500,000kW and four boilers each with an evaporative capacity of 3,450,000 lb of steam per hour. Steam pressure and temperature at the turbine stop valves will be 2300 lb per square inch at 1050 deg. Fah. with reheat to 1050 deg. Fah. Commissioning of the first generating unit in the West Burton station is scheduled for 1965. When complete in 1967, with a total installed capacity of 2,000,000kW, the station will burn about 5,500,000 tons of low grade coal a year taken from the northern part of the East Midlands coalfield. The second of the two proposed stations, Holme Pierrepont, was the subject of a Public Inquiry which ended at Nottingham in January. If approved, this station would absorb a similar tonnage of coal from the southern part of the coalfield.

[Reply Card No. E3092]



Double-ended lathe for turning tapers on mating components such as the bodies and plugs of taper valve cocks

SHORTER REPORTS *(continued)*

Square Wave Pulse Switch

Six microswitches, each capable of producing a single square pulse of a specific width when operated, are now available from Honeywell Controls, Ltd., Greenford, Middlesex. Pulse widths range from 0·1 to 10 microseconds and are unaffected by the speed of operation of the switch. When the switch is closed, a capacitor is charged through a normally-open circuit ; this switches a square-loop core which produces an output pulse to the load. Release of the switch discharges the capacitor and resets the core ; the negative voltage produced is blocked by a diode. In the normal (unoperated) condition, the circuit is isolated from the power supply so that there is no power drain during standby.

All components in the circuit package are potted for physical and environmental protection ; the switch will operate in ambient temperatures between −65 deg. and 185 deg. Fah.

The assemblies can produce voltages up to 180V and drive loads as low as 5 ohms. They are made for inputs up to 90V d.c. We illustrate

Microswitch containing magnetic core and capacitor circuit for single-pulse output

a pushbutton pattern measuring 2½in overall. Similar toggle switches are also available.

[Reply Card No. E3101]

Flexible Couplings

A recent addition to the power transmission equipment made by the Motor Gear and Engineering Company, Ltd., High Road, Chadwell Heath, Essex, is the " Essex-Lovejoy " flexible coupling, which is being produced under an arrangement with the Lovejoy Flexible Coupling Company of the United States. This design of coupling is available in eleven sizes with transmission capacities from 0·003 h.p. at 100 r.p.m. to 60 h.p. at 3600 r.p.m. The smallest size coupling, which weighs about 1 oz, is ⅝in diameter by ¾in long and the largest, 5in diameter by 6in long, weighs 21 lb.

These couplings are of simple design consisting of two hubs with the projections of a central synthetic rubber load-transmitting spider interposed between opposed jaws in the hub faces. In addition to their capacity for transmitting varying or pulsating loads for long periods without need for maintenance, the couplings are designed to compensate for small amounts of axial misalignment in the shafts or up to 1¼ deg. of angular displacement. The smaller sizes of couplings have die cast zinc or aluminium hub members and in the largest size, which we illustrate, the hubs are of cast iron. All couplings with bores over ¼in diameter have standard keyways and, unless otherwise specified, setscrews are fitted to all sizes.

Flexible coupling comprising two shaft hub members with a rubber load transmitting spider

[Reply Card No. E3102]

Industrial Films

The second film in the " Industrial Notebook " series made for Shell-Mex and B.P., Ltd., Shell-Mex House, Strand, London, W.C.2, deals with the iron and steel industry, and contains a certain amount of historical material as well as many shots taken in modern iron and steel works and of typical present-day uses of steel. The film, which is available in both 16mm and 35mm gauges, starts with a view of the world's first iron bridge, built in 1779, and goes on to show the blast-furnace at Coalbrookdale, near the bridge, in which the iron was made for this pioneer structure. By contrast, casting is shown in progress at a modern blast-furnace, and a similar review of progress is provided by showing the early cast iron rails of 1767, cast at Coalbrookdale, and the laying of 300ft lengths of prefabricated rail and its welding into continuous track by British Railways. Progress on the mechanical engineering side of iron and steel manufacture is represented by views of some old beam engines followed by a shot of one of the few very large steam rolling mill engines still in use, and finally by some views of very modern plant at Lackenby and Ebbw Vale. Ironstone mining provides an example of the basic raw material of steelmaking and of the use of steel itself, for this section of the film is illustrated by means of the very large dragline at Corby. Numerous examples of the way steel is used in building, civil engineering, railway electrification and shipbuilding are also shown in the film, which runs for twenty-seven minutes.

The Glass Manufacturers' Federation has made a new colour film entitled " Well I'm Blowed," dealing with the glass container industry. The processes involved in making glass containers are shown from the raw materials being mixed and fed into the furnaces, the molten glass extruded into the moulds of fully automatic machines and finally the containers passing through the annealing lehrs for gradual cooling and inspection. Part of the work of the Department of Glass Techology at the University of Sheffield and the British Glass Industry Research Association is also illustrated.

A new colour film, entitled " Taking Stock," produced by John Laing and Son, Ltd., 4, Regent Street, London, S.W.1, was shown before an invited audience in London recently. The film surveys some of the important construction projects undertaken by the Laing Organisation over the last ten years in Great Britain and overseas. It includes references to the erection of houses and flats in " Easiform " and traditional construction ; schools, colleges, industrial buildings, power stations, research establishments, office buildings, and civil engineering works. The film is in 16mm " Ektachrome " and runs for thirty-one minutes.

Various applications of I.C.T. 1200 Series computers are shown in a film, " Satisfied Users," which has been produced for I.C.T. by Cinechrome, Ltd. The presentation is in the form of a series of interviews with users in industry, agriculture, telecommunications and local government, the uses illustrated ranging from production planning and stores control to staff pay and costing calculations for the corporation of a seaside resort. Background material on the activities behind the figures handled by the computer provide numerous arresting sequences. The film, in " Ektachrome " 16mm sound, runs for thirty minutes and is available on free loan from International Computers and Tabulators, Ltd., Publicity Division, 149, Park Lane, London, W.1.

Transistorised Cam Pick-off

Electronic switching in synchronism with the operation of machinery, requiring no physical contact between cam and switch, is provided by the 400 series of transistorised cam pick-offs introduced by Servo Consultants, Ltd., 18, Bouverie Place, London, W.2. The tip of the pick-off contains an encapsulated coil which normally carries a current of about 6mA. A cam of magnetic material is driven by the mechanism with which some external operation is to be synchronised, and is positioned so that there is normally a gap of up to 0·03in between its periphery and the pick-up. A cut-out in the cam increases the gap to over 0·25in when passing the pick-off. The change in the field surrounding the coil between these two conditions is used to switch a transistor between its conducting and non-conducting states and connect the load to the power supply (7V–10V d.c.).

Transistor switch for non-contact cam operation

The pick-off is supplied in three forms, Types 400, 401 and 402, depending on the load to be operated, the transistors being selected according to the load characteristics and the speed of switching required. The Type 400 pick-off is intended to operate electronic equipments where relatively high output impedance and smooth transition between the two limits of output voltage are acceptable. Type 401 will operate electro-mechanical devices and warning lamps requiring rather more power, and Type 402 has a rise time of approximately 35 microseconds for operating fast electronic counters and logic stages. Dimensions of all units are 6½in long by 1½in diameter, with mounting plate measuring 3in by 2in.

[Reply Card No. E3104]

Silicon Rectifier Stacks

Medium power silicon rectifier stacks of a new range for outputs up to 3·75kW in the single-phase, half-wave and single-phase bridge connections, and up to 5kW in three-phase bridge, are announced by the International Rectifier Company (G.B.), Ltd., Hurst Green, Oxted, Surrey. The rectifiers are intended for power supplies in equipment such as power amplifiers, radio transmission equipment, computers and so on. They are stated to have efficiencies of up to 98 per cent, so that heating problems are reduced and cooling fins measuring 2in by 2in suffice for the ratings mentioned. The high output to size ratio makes them easily interchangeable in existing equipments, and minimises space requirements in new designs of apparatus. A similar range of rectifiers with 1½in by 1½in cooling fins can be supplied for current ratings 65 per cent. of the above.

[Reply Card No. E3105]

INDUSTRIAL NEWS

Venezuelan Trade Mission

The Western Hemisphere Exports Council announces that twelve of Venezuela's leading businessmen and industrialists arrived in Britain on Sunday, February 19, on a fourteen-day fact-finding tour of British industry. Lord Rootes, chairman of the Council, referred to the mission as one of the most significant ever to come to this country from Latin America. The visit has been jointly sponsored by the Board of Trade and the Western Hemisphere Exports Council, and the members of the party represent all sections of Venezuelan industry and commerce, including power and development corporations and the building and textile industries. Bankers and insurance executives are also in the party.

Members of the mission are being shown a cross-section of British industry at work, including atomic energy plants, heavy electrical and engineering factories, motor manufacturing plants, textile and steel mills, city finance and insurance houses, chemical plants and research institutions. In addition they are meeting individual manufacturers and exporters, and it is planned that they will also have talks with officials of the Government.

It is hoped, the Council says, that their visit will lead to an increase in trade between Britain and Venezuela—potentially one of the most rewarding markets in Latin America, which as a whole provides vast opportunities for British industry.

The visit is the first to be sponsored by the Western Hemisphere Exports Council (formerly the Dollar Exports Council), which was recently expanded to cover all the markets of the Western Hemisphere instead of, as before, just the dollar areas.

Exports to the Middle East

There is much evidence that, although United Kingdom firms have won many successes in Middle Eastern oil states during the 1950s, some of their competitors—particularly Western Germany and Japan—have been quicker to seize opportunities, according to an article in the current issue of the *Treasury's Bulletin for Industry*. In 1958 the total import market of these states was worth about £35,000,000 monthly, of which well over four-fifths was supplied by United Kingdom, United States of America, W. Germany, Japan, France, Belgium–Luxembourg, Italy and the Netherlands. Between 1954–56 and 1957–59 exports to the area by these countries increased by 56 per cent to a monthly average of £29,200,000. W. German exports increased by 119 per cent to a monthly average of £5,400,000, and Japanese exports by 77 per cent to £2,900,000. The United Kingdom and United States remained major suppliers, the Treasury points out, but their trade increased less than the average for the eight countries named : United Kingdom exports increased by 45 per cent to a monthly average of £8,800,000, and United States exports by 33 per cent to £7,200,000. The trend for the United Kingdom is worse than appears from these figures, the Treasury adds, since peak exports were reached in 1957 and there were falls in both 1958 and 1959. Measured as a percentage of total sales by the eight main suppliers, United Kingdom exports were 34·4 in 1957, 28·6 in 1958 and 28·3 in 1959.

United Kingdom exports of manufactures, which form over nine-tenths of its total sales to the area, were up by 46 per cent between 1954–56 and 1957–59. There were above-average increases for metal manufactures, machinery, iron and steel, and chemicals, and below-average increases for road vehicles and aircraft. United Kingdom sales of cars and commercial vehicles, including chassis and parts, increased to a monthly average of £590,000 ; but this result must be considered disappointing, the Treasury says, in view of the market opportunities.

Between January–September, 1960, monthly average United Kingdom exports of manufactures were 6 per cent below 1959. These results are disquieting, the Treasury says, in that they continue the decline of 1958 and 1959.

With the prospect of increased foreign exchange earnings, the Middle Eastern oil states as a whole constitute a market well worth a keen sales effort, the Treasury states. In this market, as in others, prices and delivery-periods are of cardinal importance in successful selling. But there are other points, the Treasury suggests, where improvements might lead to better results for the United Kingdom ; among them are the quality of local representation, advertising methods, the presentation of products through samples and trade literature, and standards of servicing facilities, particularly for motor vehicles.

Chamber of Shipping Annual Report

The Annual Report, 1960–61, published by the Chamber of Shipping of the United Kingdom, calls attention to the reports for the two previous years, which pointed out the continuing fall in the relative share of British shipping in world tonnage and the issues facing British shipowners. The U.K. share of world tonnage is quoted as being 17 per cent now compared with 26 per cent in 1939 and 45 per cent in 1910. Liberalisation in trading relations in the sphere of visible trade is contrasted with the increasing restrictions placed upon international shipping, as effected by such policies as economic nationalism. Forty governments, the report mentions, are actively endeavouring to direct cargoes to ships of their own flag, and it is emphasised that unless such policies are discarded the competitive network of international shipping will disappear. Shipowners and traders, the report goes on, can do practically nothing to stop these trends, the solution of which is a matter for governments. The world merchant fleet, it is noted, is 3¼ million gross tons in excess of requirements : the world tonnage at mid-1960 totalled 130,000,000 tons, the increase in the year being nearly 5,000,000 tons compared with nearly 7,000,000 tons in the previous year. Tonnage increases of 2,400,000 tons under the Greek flag and of 759,000 tons, 655,000 tons and 370,000 tons to the fleets of Norway, Japan and Great Britain respectively are noted. Concerning the United Kingdom fleet, of about 21,000,000 tons gross, the report commented that the proportionate increase for the year was 1·8 per cent compared with the world figure of 3·9 per cent and that the average age had been reduced. Ships completed in 1960 are stated to total 8½ million tons gross, of which Japan's share was 1,750,000 tons with the output of the United Kingdom and Germany being 1·3 million tons and 1·1 million tons respectively. Although orders placed with British yards, the report continues, amounted to 627,000 tons compared with the 1959 total of 320,000 tons, the total order book was reduced to 3,300,000 tons from 4,200,000 tons. An early decision by the Government with respect to taxation is urged, as is also the need for flexibility in its application and the removal of anomalies.

Steel Securities

The Iron and Steel Holding and Realisation Agency has announced that final arrangements are now being made for offers for sale of securities of Colvilles, Ltd., Consett Iron Company, Ltd., Dorman, Long and Co., Ltd., John Summers and Sons, Ltd., the Steel Company of Wales, Ltd., Stewarts and Lloyds, Ltd., and the United Steel Companies, Ltd. There will be separate but simultaneous offers for sale in respect of each of the seven companies covering twelve securities. It is intended, the Agency states, that the offers will be advertised on Monday, February 27, and that application lists will open at the Bank of England, Loans Office, on Thursday, March 2, and close on Friday, March 3. The yield to final redemption is approximately 6⅝ per cent in the case of Debenture stocks, the Agency says, and 6¾ per cent in the case of the unsecured loan stock. The flat yield on the preference shares is approximately 7⅛ per cent.

Arrangements are in hand, the Agency says, whereby a consortium of bankers will underwrite the whole of the offers on terms which will provide that they will put in or procure to be put in special applications for approximately 75 per cent of their total underwriting commitment, which applications will be accepted in full except to the extent that the Agency has, before the opening of the lists, been requested to treat such special applications on the same basis as those from the public.

On completion of the offers the Iron and Steel Holding and Realisation Agency will hold no securities in Colvilles, Ltd., Consett Iron Company, Ltd., Dorman, Long and Co., Ltd., or the United Steel Companies, Ltd.

Industrial Relations in Motor Industry

The Minister of Labour, Mr. John Hare, presided at a joint meeting of the leaders of the motor industry and the Confederation of Shipbuilding and Engineering Unions at the Ministry of Labour on February 20. The meeting agreed on terms of reference for joint talks which are " to review informally industrial relations in the motor industry." The review will be in the form of a broad discussion on the present position, bearing in mind the existence of agreements and procedures of both employers and trade unions in the industry. It is the intention of the employers and trade unions that any consequential action in their respective spheres of influence should be designed to assist individual companies, work-people and trade unions in their day-to-day relations.

PERSONAL AND BUSINESS

Appointments

FERODO, Ltd., has appointed Mr. B. G. Hill as export sales manager.

SANDERS AND FORSTER, Ltd., has appointed Mr. Alec. F. Gibb as its sales manager for Canada.

MR. J. CORBISHLEY and MR. S. A. CLODD have been appointed to the board of Ekco Electronics, Ltd.

MR. R. CRANE has been appointed technical representative of the automatics division of Modern Machine Tools, Ltd.

MR. I. B. COOKE has been appointed managing director of the Industrial Fan and Heater Company, Ltd.

MR. V. W. LOWE, M.I.E.E., chief engineer of Erskine, Heap and Co., Ltd., has been appointed a director of the company.

J.I. CASE COMPANY, Ltd., announces that Mr. A. J. C. Fagg has joined the staff as sales administrator.

MR. S. MCGONIGAL, A.M.I.Mech.E., formerly sales manager of Larmuth and Bulmer, Ltd., has now been appointed general manager.

MR. JOHN CREEK has been appointed deputy managing director of Fibreglass, Ltd., in addition to his present appointment as sales director.

THE PLESSEY COMPANY, Ltd., has announced the appointment of Mr. J. M. C. Dukes, A.M.I.E.E., as technical manager of the telecommunications division.

MR. HARRY WILLIAMSON, managing director of Fischer and Porter, Ltd., has been appointed to the same post with Fischer and Porter (N.V.), The Hague, Holland also.

MR. JOSEPH MCKELL has joined the boards of Quickfit and Quartz, Ltd., and Q.V.F., Ltd. Mr. McKell is a senior executive of Tilling Group, to which both companies belong.

MR. D. L. CAMPBELL has resigned from the board of Campbell, Gifford and Morton, Ltd., on his appointment as managing director of Davy-Ashmore Export Company, Ltd.

CHAMBERLAIN INDUSTRIES, Ltd., announces that Mr. Dennis W. Gray, A.M.I.Mech.E., has been appointed works director and Mr. Richard R. Watkins has been appointed sales director.

STEIN AND ATKINSON, Ltd., states that Mr. Russell Smith, who has been chairman of the company for ten years, has retired. He has been succeeded by Mr. H. W. Howes, a director of the company.

MR. R. R. KENNAN, A.M.I.Mech.E., has joined the board of directors of Ferry-Diamond Engineering Company, Ltd. He retains his directorships of Mono Pumps Africa (Pty.), Ltd., and Mono Pumps (Australia) Pty, Ltd., and the general sales managership of Mono Pumps Ltd., London.

THOMAS ROBINSON AND SON, Ltd., states that Mr. J. H. Dex, technical director, has retired from the board of the company but continues his association in a consultative capacity. It is also announced that Mr. J. C. Graham has been appointed a director of Thomas Robinson and Son, Ltd., and Mr. D. W. Povey has been appointed a director and sales manager of the company's flour milling division.

KELLOGG INTERNATIONAL CORPORATION, London, a subsidiary of the M. W. Kellogg Company, New York, announces the appointment of Mr. Joseph W. Smith as director of contract operations. He assumes the duties of Mr. B. W. Jesser, who has been named assistant vice-president and director of engineering of the M. W. Kellogg Company in New York.

Business Announcements

MR. RICHARD SOUKOP, a director of Richard Klinger, Ltd., and sales director for the company's Sidcup, Kent, factory, is making a three-month sales promotion tour of the Far East and Australia.

STAVELEY COAL AND IRON COMPANY, Ltd., states that stockholders are being asked to agree that the name of the company should be changed to Staveley Industries, Ltd.

AUDLEY ENGINEERING COMPANY, Ltd., Newport, Shropshire, has announced that with effect from March 1, the name of the company will be changed to Audco, Ltd.

EASTERBROOK, ALLCARD AND CO., Ltd., Sheffield, in extending its depot service to Scotland. Mr. J. H. S. Lamb has been appointed manager of the new branch which will open at 74, York Street, Glasgow, at the beginning of April.

HIRD-BROWN, Ltd., 244, Marsland Road, Sale, Cheshire, has been appointed sole agent in the United Kingdom for National Semiconductors, Ltd., Montreal, Canada, makers of photo-conductive cells of the cadmium sulphide type.

MASSEY-FERGUSON (HOLDINGS), Ltd., London, announces that it has purchased the share capital of Ferguson, Ltd., of Lower Baggot Street, Dublin. It is intended that this company should be known as Massey-Ferguson (Eire), Ltd.

MR. STANLEY M. GREENING, A.M.I.Mech.E., has retired after forty-eight years with J. A. Prestwich Industries, Ltd. His services have been retained as consultant by the Villiers Group of Companies, of which J. A. Prestwich Industries, Ltd., is now a subsidiary.

MERCEDES-BENZ (GREAT BRITAIN), Ltd., has acquired a new building opposite its existing headquarters on the Great West Road at Brentford, where it will undertake all major repairs and repairs to bodywork. The firm's marine engine division will be located above the workshop.

ELGAR MACHINE TOOL COMPANY, Ltd., 172-178, Victoria Road, Acton, London, W.3, announces that its associate, Gate Machinery Company, Ltd., is now handling the sale of the following machines : Nyberg and Westerberg PLS 10 surface grinding machine ; Peddinghaus model Peddy-Shear ; and Lazatti LA-60 horizontal boring machine.

GEORGE KENT, Ltd., Luton, Bedfordshire, states that the proposed acquisition of 51 per cent of the share capital of the Tieghi Company of Milan and Lenno has been effected. A new company has been formed, Kent-Tieghi S.p.A., and this has purchased the whole of the assets and goodwill of the Tieghi Company.

JOHN THOMPSON INDUSTRIAL CONSTRUCTIONS, Ltd. (" Induscon "), a member of the John Thompson Group of Companies, has taken over the administration of the John Thompson Conveyor Company, Ltd. This re-organisation within the Group takes effect immediately, and Mr. A. T. Shaw, managing director of " Induscon," will now direct the activities of the John Thompson Conveyor Company. Coinciding with the re-organisation is the appointment as manager of the Conveyor Company of Mr. R. T. McGregor, who will also continue as sales engineer of " Induscon."

HOLLAND & HANNEN AND CUBITTS (GREAT BRITAIN), Ltd., is to extend its interests in the Midlands by the acquisition of a controlling interest in B. Whitehouse and Sons, Ltd. The company will continue to operate under its present name. The board of B. Whitehouse and Sons, Ltd., has been reformed under the chairmanship of Mr. P. Wyatt, managing director of Holland & Hannen and Cubitts (North West), Ltd. Mr. P. B. Whitehouse continues as managing director. Other members of the board from Cubitts include Mr. T. O. W. Newman and Mr. J. J. Evans. Mr. J. C. Griffiths continues as director and secretary.

BAKER PERKINS. Ltd., Peterborough, and MOLINS MACHINE COMPANY, Ltd., London, announce that arrangements have been agreed for the two companies to work together in Brazil. Approval of the Bank of England and H.M. Treasury has been granted for the present Baker Perkins factory in Sao Paulo to be doubled in size and for Molins to acquire a 50 per cent interest in the capital by providing additional machine tools and cash to the value of £125,000 approximately. The Brazilian company will, in future, operate under the title of Baker Perkins Molins do Brasil S.A.

ELLIOTT BROTHERS (LONDON), Ltd., a member of the Elliott-Automation Group, announces the formation of a new subsidiary company, Rotron Controls, Ltd., owned jointly with the Rotron Controls Corporation of Woodstock, New York. Elliotts have a two-thirds controlling interest in the new company. Rotron Controls, Ltd., will have its headquarters at the Elliott-Automation factory at Airport Works, Rochester, Kent. It will manufacture the range of flowmeters and associated equipment developed by the Rotron Controls Corporation for positive and mass-flow measurements in the oil, gas, water and petro-chemical industries and will sell these instruments throughout Europe, the Middle East and the British Commonwealth (except Canada). An important feature of the instrument is a magnetic coupling which enables indications to be transmitted to local and remote read-out devices, including mass-flow conversion units, regardless of extremely high line-pressures. Signals can be transmitted directly to data processing systems.

MR. R. P. NEWMAN, A.M.I.Mech.E., has been appointed head of the members' service department of the British Welding Research Association in succession to Mr. P. H. R. Lane, who has been appointed director of research of the Drop Forging Research Association. Mr. T. R. Gurney, A.M.I.C.E., will succeed Mr. Newman in charge of fatigue researches at the British Welding Research Association.

Contracts

SIMON CARVES, Ltd., has been awarded a contract by the West Midlands Gas Board for the supply and erection of an Otto continuous reforming plant to produce 5,000,000 cubic feet per day of town gas from commercial butane. The plant is to be erected at the Nechells Works, Birmingham.

THE ESSO PETROLEUM COMPANY, Ltd., announces that it has awarded the contract to construct a butyl rubber plant at its Fawley refinery to Foster Wheeler, Ltd. The new plant, which will have a capacity of 30,000 tons of Butyl rubber per annum, will cost about £4·3 million and is expected to come on stream in 1962.

THE BURNTISLAND SHIPBUILDING COMPANY, Ltd., has received an order from James Fisher and Sons, Ltd., for a cargo vessel of 2370 tons deadweight and having a length between perpendiculars of 241ft by 38ft 10in beam by 19ft 5in in depth. Propulsion will be by an eight-cylinder supercharged diesel engine of 1800 b.h.p. built by Klöckner Humbolt Deutz A/G.

THE MITCHELL CONSTRUCTION COMPANY, Ltd., Peterborough, has been awarded a contract by the North of Scotland Hydro-Electric Board for the construction of an access road some 4¼ miles long, a tunnel 2¼ miles long, and an underground power station for the Nant section of the Loch Awe scheme. A further contract, for building aqueducts in the Nant section of the scheme, has also been let to the Mitchell Construction Company. The total value of work for the Awe project which this company now has in hand amounts to some £2,500,000. The civil engineering consultants for the Nant section of the Awe scheme are Messrs. Babtie, Shaw and Morton.

RICHARD COSTAIN (CIVIL ENGINEERING) have been awarded a contract worth nearly £2·4 million for the construction of Balderhead reservoir for the Tees Valley and Cleveland Water Board. Construction is to start immediately and the contract is expected to take four years. The dam will be 150ft high and 3000ft long, and contain about 3,000,000 cubic yards of fill. Beneath it a concrete-filled cut-off trench will be constructed to a depth of about 120ft. The spillway will consist of a bellmouth overflow leading to a 14ft diameter tunnel. The consulting engineers are Edward Sandeman, Kennard and Partners. The Balderhead project, in conjunction with additional abstraction from the River Tees and Broken Scar, will yield 26 m.g.d.

FERRANTI, Ltd., has received orders from Imperial Chemical Industries, Ltd., and from Babcock and Wilcox, Ltd., for installations of the " Argus " computer control system. The equipment for I.C.I. is for one of that company's chemical plants at Fleetwood, Lancs., where it will take over the functions of about 100 conventional control devices. It is expected to be in operation by June this year. Babcock and Wilcox, Ltd., has ordered an " Argus " system for the Central Electricity Generating Board to control the start-up and shut-down of a 200MW boiler in the new power station under construction by the Board's Southern Project Group at West Thurrock, Essex. This will be the first application in Britain of computer control to the operation of large boiler plant.

TAYLOR WOODROW CONSTRUCTION, Ltd., has been appointed as the main contractor for a new factory to be built on a 50-acre site at Griffiths Crossing, 2 miles from Caernarvon, for Ferodo, Ltd. The cost of the whole project is expected to be £2,500,000 ; it is anticipated that a further £1,000,000 will be spent on additional plant and plant rearrangement at Chapel-en-le-Frith. The present contract is in the region of £1,750,000 and is of the " all-in-service " type, including design, construction, electrical, heating, ventilating and certain mechanical plant installations. It has only taken three months from initial briefing to final planning permission being secured and it is hoped that the factory will be ready to receive plant and equipment by the late autumn this year. Estimated date of completion of construction is April, 1962.

CONTINENTAL AFFAIRS

by Our Continental Editor

Meffrouch Barrage

AFTER four years of construction, the Meffrouch Barrage in Western Algeria is scheduled to be completed in May. The site is on the upper course of the Wadi Meffrouch, a few kilometres to the south of Tlemcen. The river is a tributary of the Wadi Isser which, after its confluence with the Wadi Tafna, reaches the sea about 50km to the north-west. Tlemcen, a town of 70,000 inhabitants in the hills some 110km south-west of Oran, for many years has been suffering from a chronic water shortage. The creation nearby of a reservoir holding 20hm³ will enable the deficit to be made good and even have a surplus for Oran which could be supplied through the Beni-Bahdel aqueduct which skirts Tlemcen a short distance to the north-west.

Above the site of the new barrage, the Wadi Meffrouch has a catchment area of 90 square kilometres, with a mean annual rainfall of 675mm. The annual intake of the reservoir amounts to roughly 21hm³. After satisfying the needs of Tlemcen and ancient irrigation rights, about 13hm³ are left over for Oran.

With its crown length of 531m and maximum height over the valley bottom of 26m, the barrage will be the largest multiple-vault dam constructed to date.

The reservoir, which will cover an area of 191ha, lies in a flat-bottomed part of the valley with gently sloping sides, 1100m above sea level. Further downstream the terrain steepens and there are several waterfalls. The subsoil consists of some 30m of limestone and dolomite of a carstic nature, with much erosion under ground. This is followed by 50m to 100m of limestone marls which are fairly watertight, and are in turn underlain by another dolomite formation about 200m thick. Where the almost impervious middle stratum reaches the surface, about 1km downstream of the site finally chosen for the dam, some of the ground water emerges in a spring, the Aïn Meharas. Although it would have been preferable to site the barrage downstream of this spring, despite the slightly greater width of the valley there, this was counter-indicated by local erosions in the subsoil which were discovered in the course of local surveys. It was therefore decided to revert to the present site where construction, particularly of the foundation, would be more economic.

The whole project comprises two stages. The first, carried out between 1950 and 1956, consisted of the construction of an aqueduct tunnel approximately 50m below the surface, together with vertical intakes by means of which it was hoped to drain off a substantial amount of ground water for the use of the town. It turned out, however, that the ground water reserves had been greatly overestimated, and that less than 1,000,000 cubic metres was in fact available.

It was therefore decided to proceed with the second stage, namely the barrage. Because of the local absence of suitable material, it was not feasible to build an earth dam. For that reason the choice fell upon a multiple-vault dam which was to have been cast in concrete in the traditional manner. As a result of the insecurity arising from the war, it was found impossible to assemble the necessary plant and to recruit carpenters and other qualified workmen in adequate numbers. In order therefore to avoid an unduly long construction period, it was decided to construct most of the dam above ground level from precast concrete parts. These prefabricated sections included all the vaults and their abutments, while the foundations and the hillside abutments—the latter taking the form of lengths of gravity dam—were cast in mass concrete.

Prefabrication had the advantage that it required a minimum of qualified staff for manufacturing and erecting the components while the bulk of the work could be carried out by locally recruited labour with the help of a comparatively modest amount of mechanisation.

Although the choice of method was dictated by circumstances, nevertheless prefabrication is considered to have important advantages from an economic as well as a technical angle. Important savings resulted from the reduction in the qualified work force and the fact that no centring or shuttering was needed. Secondly, the quality of the factory-made concrete must be considered much superior to *in-situ* concrete, in particular in a hot and dry climate, and with a structure where adequate vibration is not easy to apply. The joints were made with colloidal cement mortar, and are claimed to be superior from the point of view of water tightness to joints in *in-situ* structures which often are found to be leaking.

Injections.—In order to prevent the dam from being underflowed or bypassed at the sides, it was necessary to inject the top stratum so as to form a watertight apron. Depending upon the degree of porosity, which varied greatly from place to place, the material needed for the injections consisted of cement grouting or heavier mixtures which, besides cement, included clay, sand, and silicates. These injections were carried down into the second substratum of limestone marl, and were only necessary in the immediate neighbourhood of the dam.

Foundations.—The formation of cavities and fissures in the top stratum was most severe down to a depth of 5m to 10m, and it was judged unsafe to rely in this zone on an injection apron. Accordingly the foundations were carried to a depth of from 5m to 9m (7m on the average). The lower part of the foundation walls was 2m thick, but widened to 3·5m near the top. An inspection tunnel was incorporated by embedding 2·5m-high, precast horseshoe-shaped sections. The footings of the vaults were encastred in the topmost 1·6 metres of the foundations.

Vaults.—The seventeen vaults are all identical in shape. They are cylindrical and make an angle of 52 deg. with the horizontal. The centres of the supporting buttresses are 25m apart. Our illustration (Fig. 1) shows the cross-section of the dam and a typical section through the vault, indicating the shape and arrangement of the precast components. Fig 2. shows the site.

Each vault is built up of successive rings 1·4m wide. Except at the toe and crest where the rings are incomplete, each ring consists of thirteen elements. The extrados has a radius of 13m and the intrados a radius of 12·2m except at the abutments where the wall thickness is increased, the intrados radius being decreased to 8m.

Number and size of the precast components was determined by the available crane which could lift 7 tonnes at a radius of 15m. The nine arch segments (Fig. 3) are each 3·15m in length at the extrados ; those in the central portion of the arch are 0·8m thick while the thickness of two end segments increases towards the abutments. In the direction of the cylinder axis, the segments and abutments are 1·4m long. Recesses were provided on both the longitudinal and circumferential faces for receiving keying blocks of prismatic section ; these served the purpose of preventing the jointing mortar from being subjected to shear stresses. Adequate spaces were left for the grouting completely to fill the joint.

It was desired to erect the vaults without using centering, by locating each successive ring on the preceding one. For that reason the utmost precision in precasting was required. All components of one ring including the abutments were cast simultaneously in the same mould and were numbered carefully for re-assembly in the same order. Although altogether five moulds were employed, all the rings for the same vault were made in the same mould.

The base and intrados of these moulds were of reinforced concrete. U-channels bent to the curvature of the intrados were embedded at the bottom and top so as to have a datum for striking the concrete surface. The removable outside of the mould and the top were of steel.

The moulds were filled from dumpers with concrete made from aggregate up to 50mm size and 350 kg. of Portland cement per cubic metre. Thorough vibration was applied and when the mould had been nearly filled the top was bolted on. This carried the inverted sheet steel mould for the top recess, with the centre left clear for inserting a vibrating needle to drive concrete into the lateral recesses. Any spaces left unfilled by this procedure were subsequently injected with mortar.

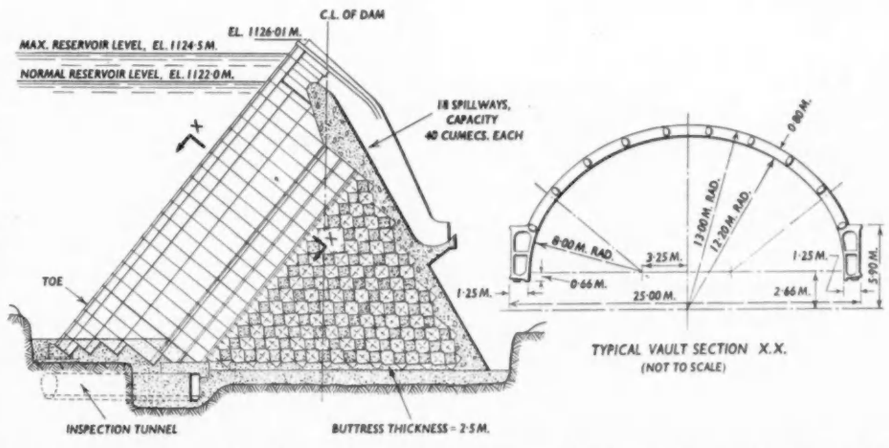


Fig. 1—Cross section of Wadi Meffrouch dam. The dam rises approximately 26m above the foundations, and has a total crown length of 531m. It comprises seventeen vaults and two gravity end sections

CONTINENTAL AFFAIRS *(Continued)*

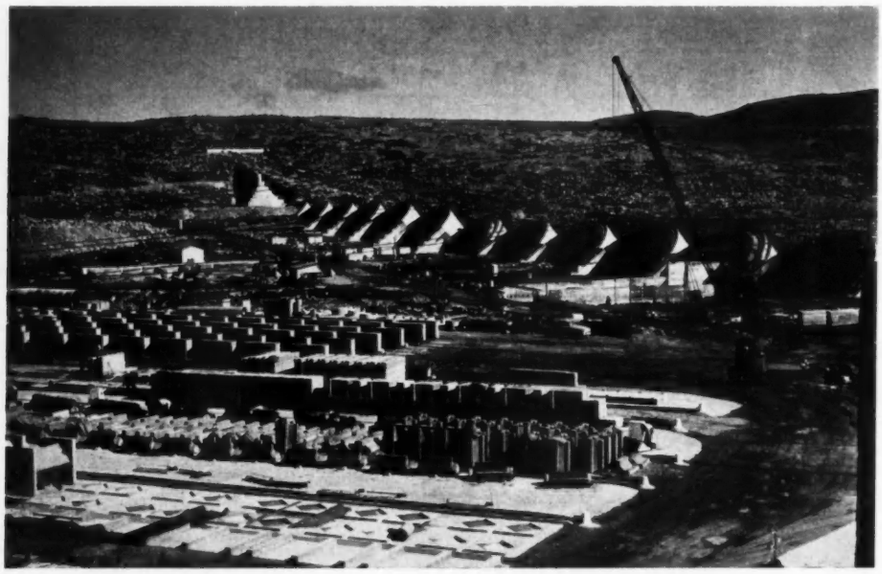


Fig. 2—View of dam under construction. In the foreground the factory area for precasting the components. A heavy mobile crane is being used for erection. The stepped core of one of the gravity dam end sections is seen against the hillside

Buttresses.—The buttresses were constructed from two precast components weighing respectively 6·6 and 6 tonnes (Fig. 4). The first was a block 0·95m by 0·95m in section incorporating at each end a separately precast, reinforced concrete slab 1·75m by 1·40m by 0·2m thick set at 45 deg. to the faces of the block. The overall length of 2·5m of this component equalled the thickness of the buttress wall. The second element was a 2m-long prismatic block with faces 0·95m and 0·31m wide set vertically at 90 and 45 deg. respectively. These blocks fulfilled the functions of keystones. The assembly was consolidated by grouting for which the necessary space was left free.

Transport of all the precast components from the factory to the dam was carried out with " Hyster " straddle carriers.

Erection.—The lowest five rings comprised respectively only three, five, seven and nine arch segments, and nine segments plus two end blocks. This constituted the toe section of the vault which rested directly on the foundations, while the succeeding rings Nos. 6 to 16 were supported on the buttress walls. The topmost four rings again shortened progressively in conformity with the slope of the structure on the air side. These rings rested laterally on an extension of the buttress wall forming a spillway.

The toe section was erected ring by ring by resting the segments on carefully lined-up concrete chairs or on one another as the case might be. The chairs were in the shape of vee-blocks with pins set in the faces sloping parallel to the vault. By means of feeler gauges inserted between the blocks and pins, the circular layout and correct slope could be adjusted to a high degree of accuracy. The toe was bonded to the foundation by drowning the bottom part of the rings in concrete. In addition, in order to avoid the possibility of cracks owing to different working of the various rings, provision has been made for axial post-tensioning by cables which are anchored and tensioned in the inspection tunnel.

The use of colloidal cement mortar was one of the key aspects of the scheme. Such mortars can be produced by mechanical agitation, chemical additives, or heat. All are extremely fluid so that they can readily penetrate narrow spaces. This property is most valuable when injecting joints with grout, or in the manufacture of thin sections where the mould can first be completely filled with comparatively coarse aggregate which is afterwards injected. The strength of the mortar can be greatly increased by dewatering under pressure. When a pressure of about 2 atmospheres is applied water oozes out of small openings in the mould or gaps in the joint, probably due to the formation of " autofilters," networks of fine material which allows water to get through while retaining the colloid. At the Meffrouch Dam, the colloidal cement mortar was mechanically produced (" Colgrout ").

In grouting the buttresses, no pressure was applied so as to avoid the need for special anchorings to hold the structure together during injection. The working stresses in these parts are, however, very moderate, and nowhere in excess of 28 kg. per square centimetre, so that the jointing did not have to be especially strong.

Before the arch joints could be grouted the hollow portions of the abutments were filled with concrete and two hoop wires were passed over the extrados and tensioned, suitable grooves for the wires having been left when casting the segments. The joints between the segments were then injected, and solidified by pressures varying from 2·5 kg per square centimetre at the base to 1·5 kg per square centimetre at the crown. Pressure was applied by means of compressed air so as to avoid the excess pressures which mechanical pumps are liable to produce.

Gravity Sections.—The structure was joined to the hillside by short gravity dams. For appearance's sake these were of the same cross section as the vault dam although this made them overstrong. However, the excess quantity of concrete used was not large. The core was carried up in diminishing rectangular sections of mass concrete, after which the precast surface slabs were erected. These then acted as permanent shuttering for concreting the intervening cavity which was filled with aggregate which was then intruded with colloidal mortar.

Spillways.—The normal impounded level will be at 1122m above sea level which is the level of the spillway crests. The highest point of the dam structure is at 1126·01m above sea level, and provision is made for the reservoir level to rise 2·5m above normal. Under these conditions the eighteen " ski-jump " spillways arranged over the buttresses discharge a total of 720 cumecs. This is comfortably above the centenary floods of 500 cumecs, especially since a certain amount of overtopping does not endanger the structure.

Contractors.—The original tender was awarded to a group of firms under the leadership of L'Entreprise Industrielle, 33, rue La Boëtie, Paris (8e). The firm chiefly responsible for the construction of the dam, in particular the methods of prefabrication adopted, was Entreprise G. Safont & Cie, Chemin d'Hydra, El Biar, Algiers.

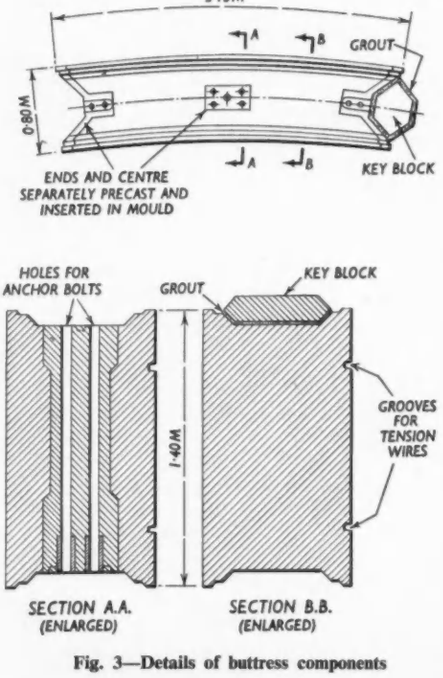


Fig. 3—Details of buttress components

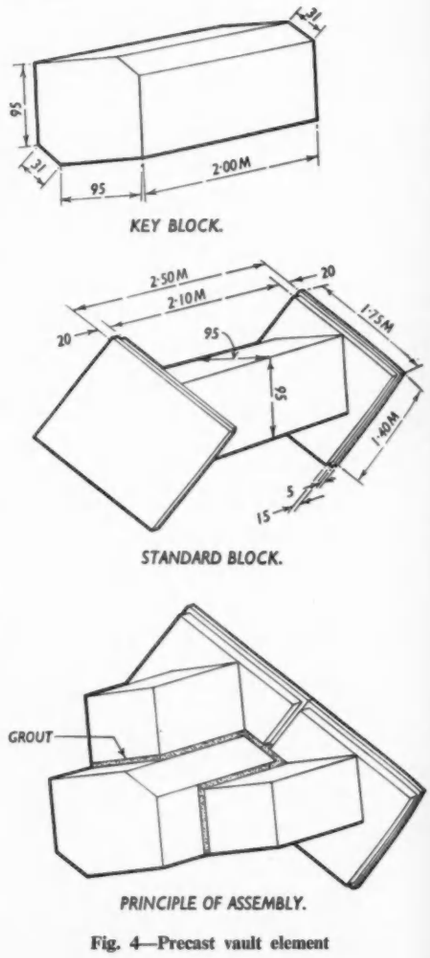


Fig. 4—Precast vault element

THE AMERICAN SCENE

By Our American Editor

Dresden Nuclear Power Station in Illinois

No. II—(*Concluded from page* 270, *February* 17, 1961)

The Dresden nuclear power station of the Commonwealth Edison Company was formally dedicated at Morris, Illinois, 50 miles south-west of Chicago, on October 12, 1960. *With a thermal output of* 625·9*MW and a generating capacity of* 180*MW, the station is believed to be the largest atomic power plant in the world. The power station was built by the General Electric Company at a cost of* 45,000,000 *dollars and employs the firm's dual-cycle boiling-water reactor. The initial reactor load comprises* 65 *tons of slightly enriched uranium fuel and is expected to last* 3½ *years. It is estimated that the new station will eventually produce power at a cost of* 0·75 *cent kilowatt-hour.*

Reactor Design

THE reactor is a forced-circulation, dual-cycle, boiling-water reactor. The dual-cycle scheme is an attempt to improve power output per unit core volume and reactor response to load demand. Both of these objectives are related to a variation in reactivity with density changes caused by boiling. In the dual-cycle reactor, boiling is controlled by the degree of sub-cooling at the inlet. To accomplish this, the steam-water mixture from the reactor is piped to a separating drum from which primary steam flows to the turbine. Saturated water flows from the drum, through heat-exchangers, and then back to the reactor. Thus, the temperature of the reactor feedwater is controlled by secondary-steam production, and the latter is controlled to meet load changes by actuation of the secondary-steam admission valves by the turbine governor. This self-regulating feature causes pressure in the secondary-steam system to vary with load. The pressure in the reactor and, essentially, in the primary steam system is held constant by the turbine regulating valve. The heat rate is, thus, contingent upon the primary-steam pressure and the percentage of power that is removed as primary steam.

The reactor pressure vessel (Fig. 8) is fabricated from molybdenum-bearing carbon steel entirely clad on the inside with stainless steel. The vessel shell weighs 350 tons and is closed with a bolted head sealed by a metal "O"-ring. Feedwater enters the bottom of the vessel through four 22in nozzles (Fig. 9), and the steam-water mixture leaves through twelve 16in penetrations near the top of the vessel shell. Additional penetrations are provided for thermo-couples, flux-monitoring devices, elements of the fuel-rupture detection and poison injection systems, pressure taps and drains.

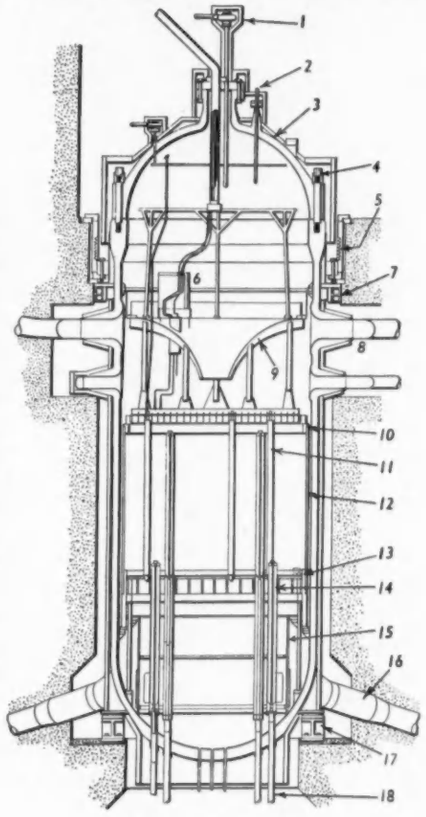
The core structure consists of three principal elements: a bottom support plate, which is mounted on a ring girder attached to columns rising from the bottom of the pressure vessel; a cylindrical guide support which also mounts on the ring girder and serves as a thermal shield; the third part is the upper guide assembly, which rests on the guide support. The bottoms of the fuel elements fit into mating holes in the support plate while the upper portions are held by the guide assembly. Channels for the control rods are formed by the spacing between fuel elements. The loaded core has an overall water-to-fuel ratio of 2·17:1. Each fuel element consists of a 4·29in square Zircaloy–2 channel 0·06in thick, in which are arranged thirty-six rods in six rows of six rods each. The fuel rods are made up by screwing together four lengths of Zircaloy–2 tubing having an o.d. of 0·56in and a wall thickness of 0·030in. End plugs welded to the 28in long segments are threaded male at one end and female at the other. No filler material or bonding agent is interposed between the fuel pellets and tubes. The active length of the fuel elements is 106in. Tie plates are attached to each end of the bundle of fuel rods and spacer plates are located at each of the three segment junctions to prevent bowing. A lifting bail is attached to the upper tie plate; the nose piece, affixed to the lower tie plate, contains an orifice for adjusting water flow through the fuel element. The tie plates, lifting bail and nose piece are fabricated from type-304 stainless steel. The overall length of the fuel element with end fixtures is 134in. The fuel bundle is attached to the square channel at the upper end by cap screws. Proper spacing between fuel elements in the core is maintained by nodes on the outside of the channels at intervals corresponding to those of the spacer plates. Allowance for thermal expansion is provided in several ways: the fuel pellets have space in which to expand in each tube segment, the segments have some freedom of movement at the quarter-way spacers, and the rods have a compressed spring at each end.

Control Rod System

The control rods have 6·5in wide blades that are 0·375in thick; their poison length is 8·5ft. Entering the core from the bottom, the rods move through guide tubes in the region between the bottom of the pressure vessel and the core support plate. They are spaced about 10in apart within an 8·25ft diameter area in the central core region. The axial flux distribution in a boiling-water reactor can be considerably distorted by boiling, with the resultant loss in moderating capacity in the upper portion of the core. This phenomenon usually results in high flux peaking in the lower portion of the core. Inserting the control rods from the bottom of the core reduces this peaking. Thus, the total peaking factor at 125 per cent of full power, including axial, radial and local peaking, is 3·66.

Each control rod has an individual drive mechanism housed in a 4in i.d. thimble attached to and extending below the pressure vessel. The drive mechanisms use reactor feedwater as the hydraulic fluid. Control rod withdrawal requires unlocking a latch mechanism by water pressure. Each drive mechanism is operated independently, and the control system is so interlocked that only one rod can be moved at a time at a rate corresponding to a reactivity change of not more than 0·013 per cent Δk/sec. The scram mechanism consists of a hydraulic accumulator for every three control rod drives. The accumulator is charged with reactor feedwater at 1400 lb per square inch, but a shuttle valve will expose the lower side of the piston to reactor pressure if accumulator pressure somehow becomes lower than reactor pressure. The total length of travel of the control rods is 8ft 10in.

The reactor containment vessel is a steel sphere 190ft in diameter with about 40ft below grade. Constructed of 3500 tons of A.S.T.M. A–201 steel plate with an A–300 specification heat-treatment, the vessel was designed in accordance with Section 8 of the A.S.M.E. Boiler Code for Unfired Pressure Vessels. With plates ranging in thickness from 1·25in at the top to 1·4in near grade, the leakage rate at the design pressure of 29·5 lb per square inch gauge was negligible. Access to the vessel is provided by three pressure locks. An 8ft by 8ft lock permits the removal of equipment from the vessel to the adjacent turbine building. Normal personnel access is through a 2·5ft by 6ft lock, and emergency escape is



1.—Vessel vent.
2.—In core flux monitor assembly.
3.—Reactor head.
4.—Reactor head stud.
5.—Bellows seal.
6.—Fuel rupture detection collector.
7.—Upper vessel guide.
8.—Steam outlet nozzles.
9.—Turning vanes.
10.—Upper grid guide.
11.—Fuel assembly.
12.—Thermal shield.
13.—Bottom core support.
14.—Control rod.
15.—Diffuser basket.
16.—Water inlet nozzles.
17.—Ring girder base.
18.—Control rod thimble extension.

Fig. 8—Sectional view of reactor pressure vessel

THE AMERICAN SCENE *(continued)*

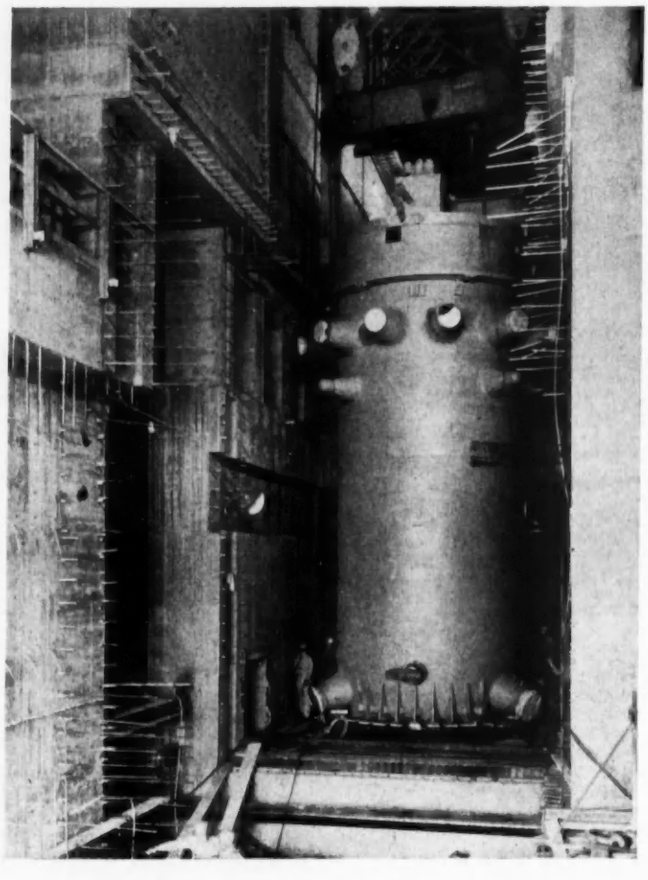


Fig. 9—Erection of reactor pressure vessel within the containment sphere

provided by another 30in diameter lock. In addition, a 16ft diameter bolted opening is used for moving equipment in and out of the vessel during shutdown periods.

Steam Cycle

As shown in the accompanying flow diagram (Fig. 10), primary coolant enters the reactor at a rate of $25{\cdot}7 \times 10^6$ lb per hour, the inlet temperature being 505 deg. Fah., and leaves as a steam-water mixture at 547 deg. Fah. for the main steam-and-water drum, where separation takes place; the steam passes to the turbine at a rate of 1,405,000 lb per hour. The water passes through the coolant circulating pumps and is returned to the reactor inlet via secondary steam generators, in which it is cooled down to the reactor inlet temperature. The heat given up in this process is used to generate another 1,191,200 lb per hour of secondary steam at about one-half the pressure of the primary steam, entering the turbine at a later stage. There are four main coolant pumps of the canned-rotor type, with 600 h.p. motors. Each pump is rated at 16,500 gallons per minute against a developed head of 103ft. The main steam drum is 7ft 11in i.d., and 67ft long. Centrifugal separators and chevron driers ensure that the moisture content of the steam does not exceed 0·1 per cent. The four secondary steam generators have vertical shells, with the primary water in an inverted " U "-tube bundle ; each is rated at 297,800 lb per hour at 510 lb per square inch absolute.

The turbine is a three-cylinder tandem compound machine, running at 1800 r.p.m., rated at 192MW with 27½in vacuum. The l.p. cylinder is a double-flow unit, and exhausts directly into the main condenser, which has a surface area of 120,000 square feet. If necessary, steam can be dumped at a rate of 125 per cent of normal flow directly to the condenser, through a system of reducing valves and desuperheating sprayers. If, for any reason, the main condenser is not available as a heat sink, there is an emergency condenser situated above the main steam drum, in which primary heat is transferred to water which is evaporated to atmosphere. The capacity is 6 per cent of the normal reactor output so that it will deal with decay heat in an emergency, sufficient water being stored for an eight hour period.

Site Construction Work

The major site construction work involved the erection of the reactor containment sphere. Excavation for this sphere was begun in the first month of construction. The sphere erection was initiated during the fourth month of construction and was completed at the end of the thirteenth month, including the pressure and leak rate testing.

The reactor containment sphere was designed, fabricated and erected by the Chicago Bridge and Iron Company in accordance with the A.S.M.E. Code for Unfired Pressure Vessels. The steel shell for the enclosure was formed in the shops from A.S.T.M. A–201 specification 6A–300 plate. All openings through the shell were made in the shop and stress relieved. The only exception was the 16ft diameter service opening which was field-fabricated and stress relieved. The individual shell plates were formed and scarfed to the curvature of the sphere. The largest plates on the equator course were approximately 10ft by 40ft and weighed 10 tons.

As the individual plates were received, they were transferred to a concave tilt table and fitted up for welding. Three or more plates were pre-assembled into sub-assemblies. Automatic welding by the twin submerged arc process was used on all pre-assembly. After each sub-assembly had been completed on one side it was transferred to a convex tilting table and welding completed on the reverse side. From this point the sub-assemblies were transferred to an X-ray stand where all seams were X-rayed. The sphere was supported by twenty columns attached to the equator course. When completed, the whole sphere, weighing 3200 tons, was supported from these columns. At this point in the sphere construction there was a 30in void between the portion of the sphere below ground and the rock.

The erection of the sub-assemblies started with the equator course, using a 100-ton derrick crane. This course was pulled and guyed into a perfect circle before the other courses were placed. The erection sequence was from the equator through the lower hemisphere, then from the equator through the upper hemisphere. As the sub-assemblies were fitted up in place, they were welded using a low-hydrogen rod with a small amount of preheat. Again all welds were X-rayed using portable X-ray equipment. Upon completion of erection, all permanent openings in the sphere were temporarily blanked off and the vessel pressurised to 37 lb per square inch gauge. During this operation no personnel were allowed within 1200ft of the centre of the sphere, necessitating a complete shutdown of the job for two days. The test pressure was held for one hour and then reduced to the design pressure of 29·5 lb per square inch gauge, at which time personnel were allowed to resume work. All seams and openings were checked for leakage using the soap bubble method. Following this, a leak rate determination test was made using a sealed

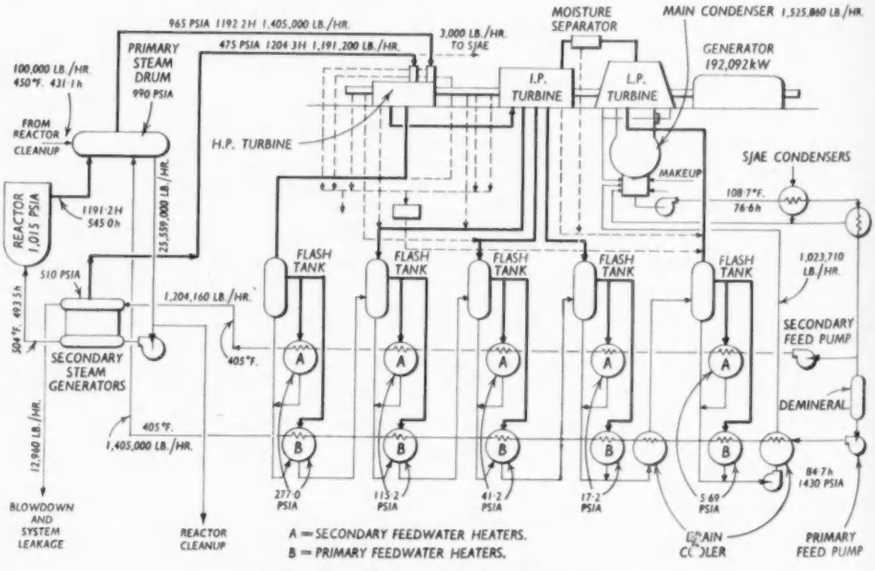


Fig. 10—Flow diagram of Dresden power station

reference system installed within the sphere for comparison in computing loss of pressure in the sphere itself. Leakage was negligible and far below the allowable value.

Pressure was then reduced to atmospheric; and two large construction access holes, one 22ft by 29ft and the other 24ft in diameter, were cut in the shell to allow construction to start on the interior concrete and on the installation of the nuclear steam supply piping and equipment. The plates for these openings were match-marked and stored and were welded back in place after all interior work had been completed. The sphere was subjected to further testing after all sphere penetrations had been installed and the interior equipment erected.

TABLE II—*Dresden Power-Test Programme*

Test	Purpose
Prepare for startup	Complete pre-operational, initial loading and low-level-test programmes.
Recirculation pump	Determine core flow and system pressure-drop characteristics.
Shutdown and safety	Test safety system and capability of plant for safe operation.
Reach critical and initial nuclear heating	Start reactor and bring to temperature while providing conditions for other tests.
Temperature coefficient of reactivity	Find $\Delta k/k$ per deg. Fah. and critical rod patterns *v.* temperature.
Rod pattern	Find near-optimum rod configuration for flux shaping.
Stability	Predict stability at next power step and as function of void fraction.
Turbine	Bring turbine to speed and set controls.
System	Determine response and stability of pressure regulator, turbine governor, and reactor (these constitute the control loop).
Single and dual-cycle	Determine plant stability at greater than rated voids in the core. Determine response and manoeuvrability of the dual cycle.
Plant performance	Part-to-full-load performance. B.Th.U./kWh and equipment-performance specification.
System expansion and vibration	Determine adequacy of expansion and vibration provisions.
Xenon peak	Obtain peak Xe value and high Xe concentration startup information.
Radiation monitoring	Determine adequacy of shielding and verify shielding calculations.
Water treatment	Maintain specified water quality and conditions.

Operating Experience

The overall performance of the Dresden plant so far has been remarkable. Power output reached the rated power with margin, and reactor stability has been demonstrated under all operating conditions, including normal and simulated disturbances, and even at voids greatly in excess of design. The ability to control easily and measure core power distribution has been proved. Tests also demonstrated the feasibility of the full diameter pressure vessel head opening and the underwater fuel handling system, which permits easy maintenance and repair of radioactive core components. The measured radioactivity levels in the turbine plant are lower than anticipated, and indicate that the present shielding is more than adequate. The results of the heat rate tests conducted earlier demonstrated that the plant is capable of operating under rated steam flow and vacuum conditions with a net power generation to the grid system of 182MW and with a gross thermal power of 621MW (this rating was used as a base point for the heat balance readings even though the plant was successfully operated at 629MW). Tests and operation to date indicate that the plant can operate under steady state conditions at 185MW (e) net without exceeding the licence limitation of 630MW thermal power. Details of the power test programme initially conducted at Dresden are listed in Table II.

The stability characteristics of the plant have proved to be excellent. No instabilities of any type were noted, nor were any trends of an approach to instability noted. Stability was demonstrated throughout a whole series of system transients intentionally induced, including a turbo-generator trip-out, complete reactor isolation and scram, oscillation of control rods, intentional pressure disturbances, and trip-out of the recirculating pumps. Instrument readings in the in-core ion chambers and riser gamma detectors indicated very stable performance up to full power, from both the standpoint of core nuclear-hydrodynamic phenomena and riser flow phenomena. Furthermore, tests conducted following initial full power operation to determine the maximum primary steam production capabilities detected no instabilities even with the steam flow rates as high as 137 per cent of rated flow. The rated core voids at full power are about 10 per cent, while for this test voids were about 18 per cent, nearly twice the design rating.

Core and fuel assembly gamma radiation scanning showed the flux pattern throughout the core to be flatter than expected, indicating that design peak-to-average calculations resulted in some margin below limits. The performance of the in-core monitors at Dresden—the first American full-scale application of these devices—has been encouraging. There are sixteen assemblies of four chambers, each mounted vertically, with the system connected in the scram circuit so that high readings will shut down the reactor. Response to neutron flux changes has been essentially instantaneous, and sensitivity was as predicted. Based on experience with the in-core instrumentation system, the control rod system, and the dual-cycle system, there is considerable optimism that power shaping and flattening at Dresden can be readily accomplished over the life of each core. If the in-core monitor system proves to be reliable over the long term, the margin requirements on void contents and burnout ratios could be reduced to permit future reactors to give more output per unit volume, thus reducing capital costs.

The ease of power flattening, measurement and control is perhaps best illustrated by the manner in which full power was first reached. The reactor was operating at about 550MW (t) with an established rod pattern. Secondary steam flow was increased until it was noticed that two in-core monitors were reading higher than desired. Adjustments in the control rods were made to trim up the distribution, and secondary steam was increased again. When full power was reached, no in-core monitor reading exceeded 90 per cent of the maximum expected peak heat flux.

The dual-cycle load-following characteristic of the station has been extensively tested and

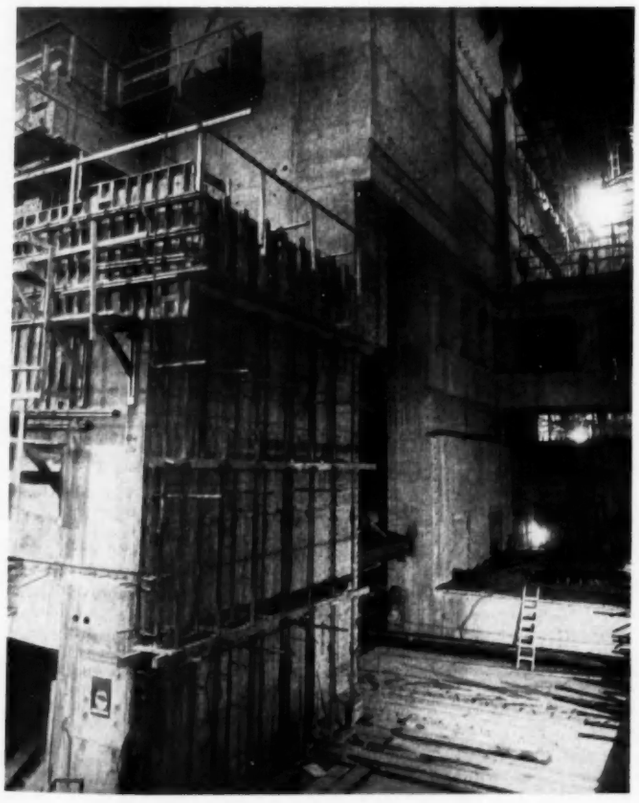


Fig. 11—Reinforced concrete shielding structures placed within the containment sphere prior to reactor vessel erection

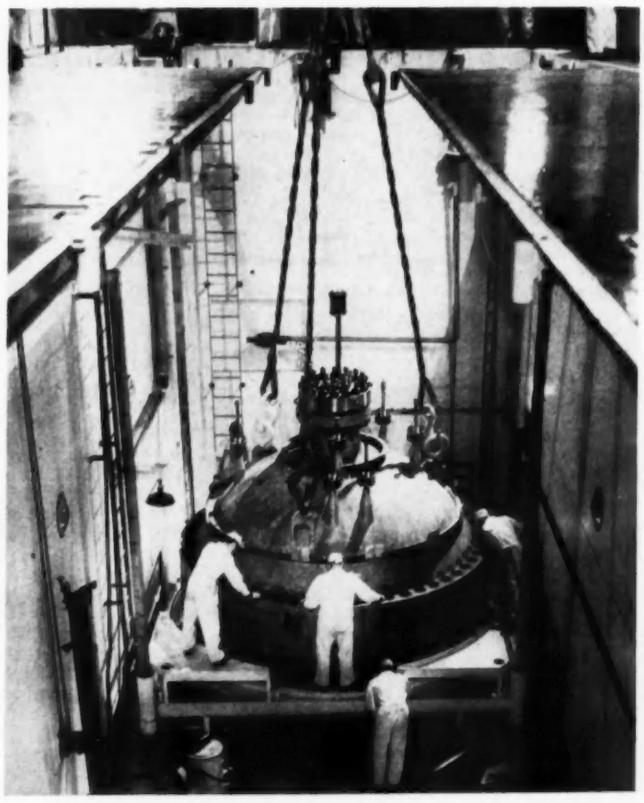


Fig. 12—50-ton head of the reactor pressure vessel being bolted in place before start-up of the reactor

THE AMERICAN SCENE *(Continued)*

demonstrated. International rapid changes in turbine governor setting showed that the reactor possesses excellent load following characteristics. With fixed control rod positions, smooth power regulation from 55 to 100 per cent of rated power was possible with secondary steam flow control only. In this type of operation it was possible to preset the control rod pattern to slant the reactor flux toward the top of the core at 55 per cent power and increase power to 100 per cent on secondary steam flow with the flux flattening itself automatically at rated power. The fact that a fixed electrical output could be maintained automatically, regardless of xenon transient effects, was further demonstrated. Reactor operating experience also indicates that the dual-cycle control characteristic curves are fairly insensitive to reasonable variations in control rod patterns, and that the dual-cycle design provides a stable, automatic load-following reactor system.

A number of routine and special maintenance, fuelling and handling operations were carried out during the Dresden power test programme. The full diameter vessel head was hoisted into place after the initial core loading of 448 fuel assemblies was complete. The head maintained seal integrity with no leaks during hydrostatic tests, initial operation and power testing. A complete radioactive fuel handling operation was demonstrated at the half-power shutdown. Eighty-four fuel bundles in the core were engaged in the fuel grapple and raised out of the core for gamma probing, and then returned. All sixteen radioactive in-core monitor assemblies were removed from the vessel in an underwater operation which proved that special elaborate handling tools were unnecessary. A control rod drive mechanism also was replaced following the half-power run with no radioactivity difficulties encountered and with the vessel full of water and the fuel loaded in the core.

Radioactive steam goes directly to the turbine, and therefore the shielding requirements in this part of the plant could not be exactly specified in advance, primarily because the extent to which radioactive N^{16} and O^{19} remained in the steam was not accurately known. Radioactivity in the steam and condensate system of the plant, however, has been significantly less than contemplated during design. The concrete shielding thicknesses actually needed around representative components of the Dresden system are less than originally contemplated, no shielding of the turbo-generator being required. The radiation levels at the turbine during full power are in the range of 10 mr to 60 mr per hour, which permits normal inspection of bearings, &c. The dose rate at the generator collector rings is less than 0·5 mr per hour.

The most significantly low radiation levels are around the condenser water boxes (3 mr per hour) and beneath the hot well (20 mr per hour). The "hot" spots, from a radiation standpoint, are locally on the condenser where 200 mr per hour is measured on the off-gas take-off, and in the shielded air ejector room where the concentration of N^{16} in the gases is increased and the radiation levels reach 1 r per hour. The fission gas activity discharged through the stack has been only about 100 microcuries per second at full power. This is several orders of magnitude lower than the maximum American allowable release to the atmosphere (700,000 microcuries per second).

The vibration and thermal expansion of the reactor, riser and steam drum system also has been satisfactory, and within the design limits during both transient and steady state operation. During the test programme, accelerometers and strain-gauges located on the risers connecting the reactor vessel and the high drum indicated barely detectable vibration and stresses. Tests to date also indicate that the recirculation flow with all four pumping loops in operation is about 10 per cent higher than the design value of $25{\cdot}6 \times 10^6$ lb per hour. With modified control rod guide tubes, core by-pass flow is estimated to be about 8 per cent as compared with the design value of 5 per cent. Thus, core recirculation flow is probably about 7 per cent higher than the design value. Natural recirculation flows of about 50 per cent of the rated forced circulation flow have been obtained through the pumping loops without any of the pumps in operation, indicating the continuation of substantial coolant flow in the event of unplanned pump trip-off situations.

Cracking of Fuel Cladding

Probably the most serious difficulties encountered at Dresden have been (*a*) the failure of three control rod drives which led to a modification of the 80 rod drives of the reactor, and (*b*) defects discovered in the Zircaloy fuel cladding tube walls. A modified eddy current testing procedure used by General Electric revealed that a small percentage of the fuel segments had small crack imperfections in the wall of the Zircaloy cladding, not detectable by the original inspection procedure. Seventy per cent of the fuel had already been shipped to Dresden; nevertheless, it was decided that the elements should be subjected to the new test. Consequently, all the elements at Dresden were returned to San José, California, for retesting, and the overall rejection rate was 3 per cent.

Zircaloy–2 cladding was chosen for the first fuel load of this plant with full knowledge of the risks involved. Zirconium has excellent nuclear characteristics, but it is still a very new and undeveloped material. Various tests have been performed with zirconium on critical assemblies, developmental and prototype reactors. However, it is not possible to develop zirconium-clad fuel to its maximum usefulness until it has been operated in a full-scale station, under temperatures and pressures and control conditions available only in a full-scale plant.

After operating continuously for twenty-seven days, the power station had to be closed down on November 15, 1960, because of the breakage of a tube connecting one of the control rod poison blades to its drive mechanism. The reactor head was removed and the broken rod removed, but 3½ft of the broken 12ft tube remained attached to the rod. The rod was pulled out of the top, and the remainder of the tube had to be taken out of the bottom with the drive mechanism. Examination showed that the broken tube had failed due to stress corrosion cracking of its precipitation-hardened stainless steel; a second, unbroken, drive tube examined also showed some evidence of cracking. It was therefore decided to replace all eighty tubes with connections of a different alloy. Fortunately, radiation was not a factor, as the radiation levels in the area of failure are relatively low.

Biologically Isolated Mill

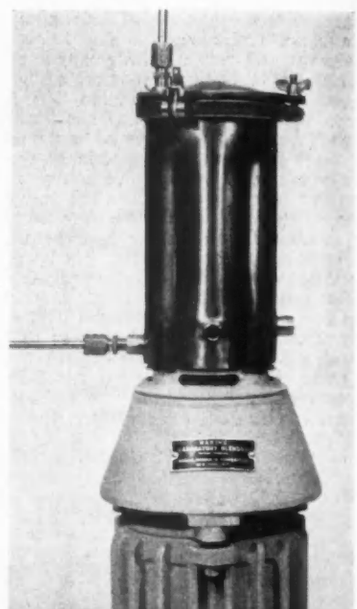
When blending infected animal and human tissues at high speeds in a mixer or blendor running at 8000 to 16,000 r.p.m, scientists at the United States Army Chemical Research Station (Fort Detrick), Frederick, Maryland, discovered that the operators and others in the immediate neighbourhood fell victims of the diseases affecting the tissues, such as cancer and tuberculosis.

The Waring Products Corporation, a subsidiary of the Dynamics Corporation of America, set to work to solve this problem.

It was found that the ordinary blendors created a local atmosphere containing very minute invisible particles of the diseased tissues. This, as an aerosol, would infect a wide area and eventually contaminate the whole room where the blending was done.

The solution was a completely gas-tight mixing chamber, which had no leakages at any point; this is known as the Waring Aseptic "Dispersall" Blendor Model AS-1, marketed by the Waring Division of the sister subsidiary, Winston Electronics, Ltd., Shepperton, Middlesex, in the United Kingdom. The container, which fits on to the standard 700S Waring Blendor base, has a lid whose "O"-ring gasket and three thumbscrew clamps render it gas-tight.

The difficult problem was to prevent the materials contaminating the bearing in the bottom driven agitator assembly, which drives the mixing blades. Eventually this was done by a special construction that eliminates either the upper or lower bearings of the drive acting as a fluid seal against any ingredients being blended.



Biologically active tissues can be treated in batches or continuously in the sealed chamber on this blendor

"Teflon" bearings are used throughout the "stand pipe" leak-proof agitator. An "O"-ring gasket ensures leakproofness. The three thumbscrews ensure gas-tight fitting for the lid. The inlet and outlet fittings allow continuous flow blending when required.

Ingredients may be drawn off hypodermically or by vacuum through the aspirator tube built into the lid.

The jacketed base ensures that the blending or mixing occurs at the desired constant temperature: this temperature control gives high recovery of the pathogen.

All the parts of the container are of 18-8 stainless steel and every part of the container likely to come in contact with the contents is both corrosion proof and essentially biologically inert.

The container may be sterilised in an autoclave or otherwise. It fits all standard Waring Blendor bases which accommodate the Pyrex container.

The Waring Aseptic "Dispersall" Unit has, it is believed, wide application with pathologists, viologists, bacteriologists, clinic workers, scientists and medical men, bio-engineers, the quality control of the production of vaccines, toxoids and so forth.

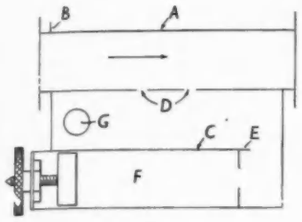
BRITISH PATENT SPECIFICATIONS

The dates printed are those of application and publication on completion. Copies of specifications may be obtained at the Patent Office Sales Branch, Southampton Buildings, Chancery Lane, W.C.2, 3s. 6d. each

ELECTRONICS

860,748. December 9, 1958.—APPARATUS FOR MEASURING ULTRA-HIGH FREQUENCIES, Compagnie Francaise Thomson-Houston, 173, Boulevard Haussmann, Paris (8e), France.

In known methods of measuring u.h.f. frequencies, movement of the adjustable portion of a turntable member is usually extremely sensitive adjacent to the resonant state and this leads to difficulties in producing the state of resonance accurately. In the present invention, as shown in the drawing, the electro-



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magnetic radiation, the frequency of which it is required to measure, is propagated in the waveguide *A* through the input end *B*, in a direction of the arrow. A proportion of this radiation is fed into the waveguide *C* via apertures *D* and passes through the end *E* into the cavity *F*. Some of this radiation is reflected back into the waveguide *C*, and the amount is dependent upon the tuning of the resonant cavity. If the cavity is tuned to resonance it will absorb all the radiation it receives and no radiation will be reflected back into the waveguide *C*. If the tuning of the cavity is displaced from resonance a proportion of the radiation will be reflected back into that waveguide and it will be detected by the device *G*, which may be a semiconductor. A minimum reading of a meter attached to *G* will therefore indicate that the resonant cavity *F* is tuned to resonance. If the ratio of the input energy to the directive coupler to the output energy from the directive coupler is equal to 30dB the minimum current detected will be approximately zero. The position of the tuning piston *H*, which can be measured directly, which produces resonance of the cavity *F* will indicate the frequency of the input radiation. The apparatus must, of course, be suitably calibrated for use. Practical experiments are stated to show that the apparatus is not sensitive to very small movements of the piston and it is therefore easy to tune for resonance of the cavity.—*February* 8, 1961.

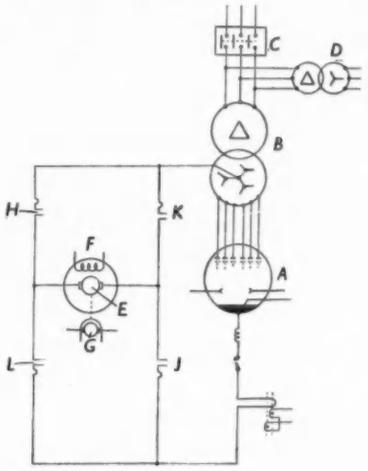
ELECTRICAL ENGINEERING

861,203. July 13, 1959.—ELECTRIC MOTOR CONTROL SYSTEMS, Canadian Westinghouse Company, Ltd., 286, Sanford Avenue North, Hamilton, Ontario, Canada.

Means are usually provided in the regulating system of Ward Leonard drives for the generator field to limit the loop current to protect the d.c. motor and generator armature. This limiting action does not however limit the power peaks which may be produced as the d.c. motor approaches full speed (i.e. full voltage) at maximum current. The peaks so produced are reflected into the a.c. circuit and may cause undesirable peak loads in the a.c. supply. One method used to overcome this problem is to use an induction motor and a flywheel as the source of mechanical energy, the inertia of the flywheel operating to smooth out undesired fluctuations. This method is, however, expensive and it is preferable to use a normal synchronous motor as a source of mechanical energy. According to this invention the limitation of peaks, and other objects, are achieved by measuring the loop voltage and lowering the permissible current as the loop voltage rises above a certain predetermined value. For this purpose the field of the Ward Leonard generator is fed from a rotary amplifier which serves as a means of combining various control functions into one direct current which is used to supply the generator field. Accordingly, the amplifier has several fields responsive to various conditions, including two current limit fields supplied from magnetic amplifiers. The operation of the circuit is described fully in the specification. As an example, a pattern voltage calling for clockwise rotation of the motor and gradually increasing speed may be applied to one winding of the rotary amplifier. If the resultant current in the generator-motor loop rises too high, one of the magnetic amplifiers energises a further winding of the rotary amplifier and reduces the loop voltage. Thus the motor will accelerate at maximum permissible current until full speed is reached. With increasing loop voltage a point is reached where the voltage from a bridge rectifier exceeds a preset voltage from a potentiometer which is adjusted to establish the peak load on the motor driving the Ward Leonard set. In these conditions a further winding on the magnetic amplifier passes a current which causes a change in current through one of the magnetic amplifier windings in such a direction as to reduce the loop current.—*February* 15, 1961.

860,431. March 6, 1956.—HOISTS AND WINDERS, Associated Electrical Industries, Ltd., 33, Grosvenor Place, London, S.W.1. (*Inventors: Leo Abram, James Sherlock, John Antony Garrod and James Patrick McBreen.*)

According to the present invention, an electrically driven hoist or winder for operation from an a.c. supply comprises a d.c. motor and a converter of the mercury arc rectifier or similar type, with provision for operation of the latter alternatively as a rectifier and as an inverter in dependence on the sense of the error in the motor speed compared with a reference quantity. Referring to the main power circuits shown in the drawing, a six-phase converter is shown



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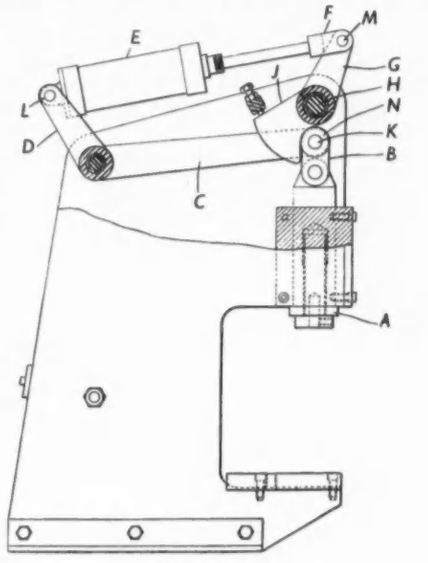
at *A*, the anodes of this converter being connected with the secondary winding of a converter transformer *B*, the primary winding of which is connected with a three-phase a.c. supply by means of a circuit breaker *C*. An auxiliary transformer *D* is connected for energising the grid circuits of the converter. The armature of the hoist motor is shown at *E* and the brushes of this motor may be connected in one direction or the other with the converter cathode and the neutral point of the converter transformer secondary winding. The motor is provided with a separately excited field winding *F* connected with a constant voltage source (not shown) of direct current. A tachometer generator *G* is coupled mechanically with the motor armature so as to produce an output directly proportional to the speed of the motor. The changeover from rectifier to inverter operation depends on the sense of the difference between the actual and the desired speed of the motor. This desired speed is indicated by a reference quantity which may be derived from movement of the driver's control lever or, under automatic control, from the position of the cage or conveyance. Establishment of the appropriate operating condition is effected by the reverse error relay method, through which the firing of the converter and the direction of connection of the motor armature with the converter by means of the forward and reverse contacts *H*, *J* and *K*, *L* respectively are controlled. The specification describes in detail the grid control circuits and the amplifier circuits employed for the control of the equipment.—*February* 8, 1961.

PRESSES

860,191. March 21, 1957.—FLUID PRESSURE-OPERATED DEVICES, Philips Electrical Industries, Ltd., Spencer House, South Place, Finsbury, London, E.C.2. (*Inventor: Robert Davidson.*)

In fluid pressure-operated devices such as power presses, vices, clamps, &c. it is frequently desirable to cause the movable member to make a quick closure movement of relatively long travel followed by a high pressure application with a relatively short travel. The object of the invention is to provide a device in which economical use is made of the pressure medium so that a given pressure may be obtained on the workpiece from the use of a power assembly of relatively small bore and/or short stroke. We illustrate one of two embodiments of the invention in a



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press suitable for operation by compressed air described by way of example in the specification. The upper end of the ram *A* is connected by a pair of links *B* to the free end of one arm *C* of a bell-crank lever pivotally mounted on the press body. The other arm *D* of the bell-crank lever is connected by a pin to one end of a cylinder *E*. The piston-rod at its free end carries a fork *F* embracing the free end of an arm *G* to which it is pivotally connected by a pin. The arm *G* is journalled on a shaft *H* carried on the frame of the press. Secured to the arm are two identical cams *J* which engage rollers *N* carried on the pivot pin *K*. Referring to the parts in the relative position as shown in the drawing the curved surface of the cam plates *J* extending to the left from adjacent the links *B* is of progressively increasing radius and constitutes the working face. When air is admitted to the cylinder the piston moves to the left relatively to apply a pull between the points *L* and *M*. As the cams are bearing against the rollers *N* the arm *G* cannot move in a counter-clockwise direction. Consequently, the cylinder slides to the right over the piston with simultaneous rotary movement of the bell-crank in a clockwise direction. As the arm *C* is longer than the arm *D* a correspondingly amplified movement is imparted through the links *B* to the ram to give a rapid movement to bring the tool into engagement with the work. Before the tool encounters the work the rollers *N* clear the lower point of the cams so that the arm *G* is no longer held against rotation. When this occurs the continuing shortening of the distances between the points *L* and *M* causes the curved surface of the cams to operate on the rollers thereby giving a slow movement for the working stroke of the press. The pressure by the cylinder is magnified to an extent determined by the contour of the curved cam surface.—*February* 1, 1961.

Forthcoming Engagements

Secretaries of Institutions, Societies, &c., desirous of having notices of meetings inserted in this column, are requested to note that, in order to make sure of their insertion, the necessary information should reach this office not later than a fortnight before the meeting. In all cases the TIME *and* PLACE *at which the meeting is to be held should be clearly stated.*

ASSOCIATION OF SUPERVISING ELECTRICAL ENGINEERS

Tues., Feb. 28.—NEWCASTLE UPON TYNE AND DISTRICT BRANCH : Crown Hotel, Clayton Street, Newcastle upon Tyne, Open Night, 7.30 p.m.

Wed., March 1.—HALIFAX BRANCH : Crown Hotel, Horton Street, Halifax, " Prismatic Lighting Equipment," K. Marshall, 7.45 p.m. ★NORTH LONDON BRANCH : Wood Green Civic Centre, Town Hall, Wood Green, N.22, Film Show, 8 p.m. ★SOUTH EAST LONDON BRANCH : Eltham Green School, Queenscroft Road, Eltham, London, S.E.9, Films, 7.45 p.m. ★PRESTON BRANCH : R.A.F.A. Club, East View, Preston, " High-Quality Sound Reproduction," J. Metcalfe, 7.30 p.m.

Thurs., March 2.—BRIGHTON, HOVE AND DISTRICT BRANCH : New Imperial Hotel, First Avenue, Hove, Sussex, " Electrical Interlocking with the Aid of Radio Isotopes," F. J. Burridge, 7.30 p.m. ★ SOUTHAMPTON BRANCH : Polygon Hotel, Southampton, " The Manufacture and Applications of Transistors," E. Wolfendale, 7.30 p.m.

BRITISH INSTITUTION OF RADIO ENGINEERS

To-day, Feb. 24.—SOUTH MIDLANDS SECTION : North Gloucestershire Technical College, Cheltenham, " Design Aspects and Characteristics of Long Distance Waveguide Communication Systems," A. E. Karbowiak, 7 p.m.

Wed., March 1.—TELEVISION GROUP : London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1, Inaugural Address, L. H. Bedford, 5.30 p.m.

Thurs., March 2.—NORTH WESTERN SECTION : Reynolds Hall, College of Technology, Manchester, " Some Typical Uses for Electronic Data Processing Systems," C. W. Baxter, 7 p.m.

CEMENT AND CONCRETE ASSOCIATION

Mon., Feb. 27.—Cambridgeshire Technical College and School of Art, Collier Road, Cambridge, " Surface Finishes of Concrete " F. Ward, 7.30 p.m.

COMBUSTION ENGINEERING ASSOCIATION

Tues., Feb. 28.—NORTH WESTERN REGION : Engineers' Club, Albert Square, Manchester, " Fuels for Modern Engines," A. F. A. Nida, 7.15 p.m.

Wed., March 1.—SCOTTISH REGION : Grand Hotel, Charing Cross, Glasgow, " The Automatic Boiler House," 10 a.m. and 2 p.m.

ILLUMINATING ENGINEERING SOCIETY

Mon., Feb. 27.—BIRMINGHAM CENTRE : Regent House, St. Phillip's Place, Colmore Row, Birmingham, Annual General Meeting, " Plastics for Lighting," W. E. Harper and " Glass for Lighting." J. G. Holmes, 6 p.m.

Tues., Feb. 28.—LONDON CENTRE : Royal Institution, Albemarle Street, London, W.1, Sixth Trotter-Paterson Memorial Lecture, " Long-Range Weather Forecasting," Sir Graham Sutton, 6 p.m.

Wed., March 1.—EDINBURGH CENTRE : Y.M.C.A. Social Room, 14, South St. Andrew Street, Edinburgh, " 25 Years of Stage Lighting," F. P. Bentham 6.15 p.m. ★ NEWCASTLE UPON TYNE CENTRE ; Room B7, Percy Building, King's College, Queen Victoria Road, Newcastle upon Tyne, 1, " Lighting and Other Things in Moscow and Leningrad," A. G. Penny, 6.15 p.m. ★SWANSEA GROUP : Demonstration Theatre, South Wales Electricity Board, The Kingsway, Swansea, " Floodlighting," 6 p.m.

Thurs., March 2.—GLASGOW CENTRE : British Lighting Council, 29, St. Vincent Place, Glasgow, C.1, " 25 Years of Stage Lighting," F. P. Bentham ; and Annual General Meeting, 6.30 p.m. ★ NOTTINGHAM CENTRE : Electricity Centre, Carrington Street, Nottingham, Presdiential Address, W. S. Stiles, 6 p.m.

INSTITUTE OF BRITISH FOUNDRYMEN

Wed., March 1.—SOUTHAMPTON SECTION : Technical College, St. Mary's Street, Southampton, " Foundry Sands and Moulding Materials," W. B. Parkes, 7.30 p.m.

INSTITUTE OF METALS

Tues., Feb. 28.—SHEFFIELD LOCAL SECTION : Applied Science Building, The University, St. Georges Square, Sheffield, " Martensite Formation," W. S. Owen, 7.30 p.m.

Thurs., March 2.—BIRMINGHAM LOCAL SECTION : College of Technology, Gosta Green, Birmingham, " Rating Sheet Metal Formability by Press Performance," D. H. Lloyd, 6.30 p.m. ★ LONDON LOCAL SECTION : 17, Belgrave Square, London, S.W.1, " Progress in the Electron Theory of Metals," J. A. Catterall, 6.30 p.m. ★ LEEDS METALLURGICAL SOCIETY : University Staff House, University Road, Leeds, " Grain Size—Three-quarters of the Key to Strength ?," N. J. Petch, 6.30 p.m. ★ LIVERPOOL METALLURGICAL SOCIETY : University Club, Liverpool, Eighth Annual Conversazione, 7 p.m.

INSTITUTE OF PETROLEUM

Wed., March 1.—61, New Cavendish Street, London, W.1, " Low-Cost Road Surfacings of Gravel Roads," T. L. Les, G. P. Richard, P. J. Way and K. G. Latham, 5.30 p.m.

INSTITUTE OF PHYSICS AND THE PHYSICAL SOCIETY

Thurs., March 2.—ACOUSTICS GROUP : Physics Department, Imperial College of Science and Technology, London, S.W.7, " Lead Zirconate—Titanate Piezoelectric Ceramics," A. E. Crawford, 5.30 p.m.

INSTITUTE OF REFRIGERATION

Thurs., March 2.—Institute of Marine Engineers, Memorial Building, 76 Mark Lane, London, E.C.3, Joint meeting with the Low Temperature Group of the Institute of Physics and the Physical Society, Symposium on " Problems of Thermal Insulation and their Solution," 2 p.m.

INSTITUTE OF ROAD TRANSPORT ENGINEERS

Mon., Feb. 27.—SCOTTISH CENTRE : North British Hotel, Edinburgh, " Wheels Round the World," 7.30 p.m.

Thurs., March 2.—WESTERN CENTRE : Royal Hotel, Bristol, " The Development of the Hovercraft," R. Stanton Jones, 7 p.m. ★ SOUTH WESTERN GROUP : Exeter City Fire Brigade, Exeter, " Fuel Developments," L. P. F. Drake, 7.30 p.m.

INSTITUTION OF CHEMICAL ENGINEERS

Tues., March 7.—Geological Society, Burlington House, London, W.1, Papers on " Fluidisation," 4 p.m.

INSTITUTION OF CIVIL ENGINEERS

Tues., Feb. 28.—Great George Street, Westminster, London, S.W.1, " Some Experiences with Prestressed Concrete Piles," S. V. Gardner and D. H. New, 5.30 p.m.

Tues., March 7.—Great George Street, Westminster, London, S.W.1, Joint meeting with the Royal Institute of British Architects, " The Problem of Housing Large-Scale Plant," W. S. Atkins and H. Lobb, 5.30 p.m.

INSTITUTION OF ELECTRICAL ENGINEERS

Mon., Feb. 27.—NORTH-EAST CENTRE : Neville Hall, Newcastle upon Tyne, " A General Theory of Depreciation of Engineering Plant," D. Rudd, 6.30 p.m. ★ S. MIDLANDS ELECTRONICS AND MEASUREMENT GROUP : James Watt Institute, Birmingham, " Electronics in Medicine," P. R. Styles, 6 p.m. ★ WESTERN UTILISATION GROUP : S. Wales Electricity Board Demonstration Theatre, The Centre, Bristol, " The Organisation of Industrial Electrical Maintenance," S. R. Phelps, 6 p.m. ★ HATFIELD DISTRICT MEETING : Technical College, Hatfield, " Magnetic Properties of Thin Films for Computing Devices," E. M. Bradley, 7 p.m.

Tues., Feb. 28.—NORTH-WESTERN SUPPLY GROUP: Engineers' Club, Albert Square, Manchester, " The Protection of High-Voltage Insulators from Power-Arc Damage," A. E. Guile, 6.15 p.m. ★ S. MIDLAND CENTRE : Town Hall, Birmingham, Faraday Lecture, " Transistors and All That," L. J. Davies, 7 p.m.

Wed., March 1.—JOINT GROUP MEETING WITH ROYAL AERONAUTICAL SOCIETY : 4, Hamilton Place, London, W.C.2, Discussion on " The Training of ' Electrical ' and ' Electronic ' Engineers for the Aircraft Industry," opened by G. S. Bosworth, 6 p.m. ★ TEES-SIDE SUB-CENTRE : Cleveland Scientific and Technical Institution, Middlesbrough, " The Application of Electronics to the Electricity Supply Industry," J. S. Forrest, 6.30 p.m. ★ RUGBY SUB CENTRE : College of Engineering Technology, Rugby, " Fundamental Particles," Abdus Salam, 6.30 p.m. ★ LONDON GRADUATE AND STUDENT SECTION : All-day visit to Vauxhall Motors Ltd., Luton, 9 a.m. ★ SOUTHERN CENTRE : S. E. Electricity Board Offices, Hove, " Public Electricity Supply—Its past and likely future Development," A. C. Thirtle, 6.30 p.m.

Thurs., March 2.—ORDINARY MEETING : Savoy Place, London, W.C.2, " The Place of Formal Study in the Post-Graduate Training of an Electrical Engineer," N. N. Hancock and P. L. Taylor, 5.30 p.m. E. MIDLAND CENTRE : De Montford Hall, Leicester, Faraday Lecture, " Transistors and All That," L. J. Davies, 7.15 p.m. ★ CAMBRIDGE ELECTRONICS AND MEASUREMENT GROUP : Cavendish Laboratory, Cambridge, " Engineering and the Brain," R. L. Gregory, 8 p.m.

Fri., March 3.—MEDICAL ELECTRONICS AND DISCUSSION GROUP : Savoy Place, London, W.C.2, Discussion on " The Clinical Value of E.E.G. Recording," and " Present Trends in General Purpose E.E.G. Recorders," opened by H. B. Morton and H. R. A. Townsend, 6 p.m. ★ NORTH-EASTERN CENTRE : Technical College, Carlisle, " Measured and Electrical Model Characteristics of Buildings Heated by Floor Thermal Storage," E. D. Taylor, B. Berger and G. Blaylock, 7 p.m. ★ SOUTH-EAST SCOTLAND SUB-CENTRE : Joint Meeting with Scottish Branch of The Institution of Mechanical Engineers : North British Hotel, Edinburgh, " Blaenau Ffestiniog and Other Medium-Head Pumped Storage Schemes in Great Britain," H. Headland, 6.30 p.m.

INSTITUTION OF ENGINEERING DESIGNERS

Thurs., March 2.—38, Portland Place, London, W.1, " Swarf Handling," H. K. Dally, 7 p.m.

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND

Tues., Feb. 28.—39, Elmbank Crescent, Glasgow, " Results of Some Systematic Stability Calculations," C. W. Prohaska, 6.30 p.m.

Fri., March 3.—Robert Gordon's Technical College, Aberdeen, Joint meeting with Aberdeen Mechanical Society, " Developments in Marine Steam Turbine Design," T. W. F. Brown, 7.45 p.m.

INSTITUTION OF HIGHWAY ENGINEERS

Thurs., March 2.—YORKSHIRE AND LINCOLNSHIRE BRANCH : Visit to Yorkshire Tar Distillery, Knottingley, and Paper on " Recent Developments in Road Construction and Maintenance with Tar," P. S. Ledger Lee, 2.30 p.m.

Fri., March 3.—NORTHERN BRANCH : The Courts, Carlisle, " Surface Dressing," 6.30 p.m. ★ LONDON BRANCH : Institution of Structural Engineers, 11, Upper Belgrave Street, London, S.W.1, " Lessons Learned on the Design, Construction and Maintenance of Motorways—(iv) From the Ministry of Transport Angle," 5.30 p.m.

INSTITUTION OF MECHANICAL ENGINEERS

To-day, Feb. 24.—EAST MIDLANDS GRADUATES' BRANCH : Visit to Metalastick, Ltd., Evington Valley Road, Leicester, 7 p.m. ★ NORTH WESTERN GRADUATES' BRANCH : Visit to Agecroft Power Station, Manchester, 7 p.m.

Sat., Feb. 25.—MIDLAND GRADUATES' BRANCH : Visit to British Oxygen Gases, Ltd., Wolverhampton, 9.45 a.m. ★ COVENTRY GRADUATES' A.D. SECTION : Visit to Hams Hall " C " Power Station, Lea Marston, Sutton Coldfield, 10 a.m.

Tues., Feb. 28.—STEAM POWER PLANT GROUP : I, Birdcage Walk, Westminster, London, S.W.1, Discussion on " The Advantages of Increased Pressures and Temperatures and Ratings of Large Steam Power Plant," opened by J. C. London, 6 p.m. ★ SOUTHERN BRANCH : Huntley and Palmer, Ltd., King's Road, Reading, " Radio Isotopes in Engineering," W. G. Busbridge, 7.45 p.m. ★ EASTERN GRADUATES' SECTION : Visit to Bedford Waterworks, 7.30 p.m. ★ SCOTTISH GRADUATES' SECTION : Visit to North British Rubber Company, Ltd., Castle Mills, Edinburgh, 3, 7 p.m. ★ SOUTHERN GRADUATES' SECTION : College of Technology, Anglesea Road Annexe, Portsmouth, " Radio Telescopes," B. R. Cox, 6.30 p.m. ★ BIRMINGHAM A.D. CENTRE : James Watt Memorial Institute, Great Charles Street, Birmingham, " Research into Brake Usage in Passenger Cars and A Test Schedule for Passenger-Car Brakes," D. F. Woor, A. E. Livsey, A. F. Prestidge, 6.30 p.m. ★ WESTERN A.D. CENTRE : Royal Hotel, Bristol, " Mechanical Design Aspects of the Comet," F. W. Morley, 6.45 p.m.

Wed. and Thurs., March 1 *and* 2.—1, Birdcage Walk, Westminster, London, S.W.1, Symposia, " User Experience of Large Scale Industrial Vacuum Plant," 6 p.m.

Wed., March 1.—EASTERN BRANCH : Dujon Restaurant, 34, High Street, Bedford, Thomas Lowe Gray Lecture, " The Early Development of the Dracone Flexible Barge," W. R. Hawthorne, 7.30 p.m. ★ YORKSHIRE BRANCH : Afternoon Visit to Hopkinsons, Huddersfield, " The Potentialities of Accurate Measurement and Control in Engineering," J. Loxham, at the George Hotel, Huddersfield, 7 p.m. ★ EASTERN GRADUATES' SECTION : Visit to Flowers Brewery, Luton, 6.30 p.m.

Thurs., March 2.—E. MIDLANDS BRANCH : College of Technology, Chesterfield, " Mechanical Handling Equipment and its Application," F. T. Dean, 7.15 p.m. ★ SCOTTISH BRANCH : Royal College of Science and Technology, Glasgow, Annual General Meeting, " Blaenau Ffestiniog and Other Medium-Head Pumped Storage Schemes in Great Britain," H. Headland, 7.30 p.m. ★ WESTERN BRANCH : The University, Bristol, Annual General Meeting, " Research and Development in the Field of Nuclear Engineering," W. B. Hall, 6.30 p.m. ★ YORKSHIRE GRADUATES' SECTION : Grand Hotel, Sheffield, Chairman's Address, " What is a Ship Tank Carriage," S. B. Fielding, 6.30 p.m.

Fri., March 3.—SCOTTISH BRANCH : North British Hotel, Edinburgh, " Blaenau Ffestiniog and Other Medium-Head Pumped Storage Schemes in Great Britain," H. Headland, 7.30 p.m.

INSTITUTION OF PLANT ENGINEERS

To-day, Feb. 24.—WESTERN BRANCH : Grand Hotel, Broad Street, Bristol, Ladies' Night, 7.15 p.m.

Mon., Feb. 27.—WEST AND EAST YORKSHIRE BRANCH : Houldsworth School of Applied Science, The University, Leeds, " Fuel-Economy and Productivity," K. Higginson, 7.30 p.m.

Tues., Feb. 28.—EDINBURGH BRANCH : 25, Charlotte Square, Edinburgh, Annual General Meeting, 7 p.m. ★ SOUTH WALES BRANCH : South Wales Institute of Engineers, Park Place, Cardiff, " Industrial Lighting," R. S. Hazell, 7.30 p.m.

Wed., March 1.—GLASGOW BRANCH : More's Hotel, India Street, Glasgow, Annual General Meeting, 7.15 p.m. ★ SOUTHERN BRANCH : Polygon Hotel, Southampton, Annual General Meeting, 7.30 p.m.

Thurs., March 2.—NORTH EAST BRANCH : Three Tuns Hotel, Durham City, Annual General Meeting, and " Plant Engineering in a Plastics Factory," A. E. Swallow, 7 p.m.

INSTITUTION OF PRODUCTION ENGINEERS

Mon., Feb. 27.—NORTH MIDLANDS REGION : Louis Room, St. James's Restaurant, St. James's Street, Derby, " Numerical Analogue Control of Machine Tools," O. S. Puckle, 7 p.m. ★ NORTH WESTERN REGION : Reynolds Hall, Manchester College of Science and Technology, Manchester, " Business Aids to Production," J. Gelley, 7.15 p.m.

Wed., March 1.—SOUTH EASTERN REGION : Old Ship Hotel, Castle Square, Brighton, " The Economics of Material Handling," A. G. Hayek, 7 p.m. ★ SOUTH WESTERN REGION : Cornwall Technical College, Trevenson, Poole, Redruth, " Recent Developments in the Soviet Union," D. F. Galloway, 7.15 p.m.

Thurs., March 2.—ROCHESTER GRADUATE SECTION : Old Palace, Maidstone, Kent, " Operational Research," D. Hicks, 7.30 p.m.

INSTITUTION OF THE RUBBER INDUSTRY

Mon., Feb. 27.—Engineers' Club, Albert Square, Manchester, " Properties and Applications of Chlorobutyle," P. E. C. Davies, 6.45 p.m.

INSTITUTION OF STRUCTURAL ENGINEERS

To-day, Feb. 24.—MIDLAND COUNTIES BRANCH : Byng Kendrick Suite, College of Advanced Technology, Gosta Green, Birmingham, 6, " Computers and Structural Design—the Present Position and Future Trends," R. E. Rowe, 6.30 p.m.

Wed., March 1.—NORTHERN COUNTIES BRANCH : Neville Hall, Newcastle, " The Design, Fabrication and Erection of Welded Girders for the South Durham Steel and Iron Company, Ltd., Greatham," W. G. Gentry, 6.30 p.m. ★ YORKSHIRE BRANCH : Lecture Theatre, Electricity Building, Ferensway, Hull, " The Design and Construction of the New Transit Sheds at No. 12 Quay, King George Dock, Hull," R. A. Fisher, 6.15 p.m.

Fri., March 3.—WALES AND MONMOUTHSHIRE BRANCH : South Wales Institute of Engineers, Park Place, Cardiff, " Lift Slab Construction," F. R. Benson, 6.30 p.m. ★ WESTERN COUNTIES' BRANCH : Small Lecture Theatre, University Engineering Laboratories, University Walk, Bristol, 8, " Berkeley Power Station—Some Special Factors Influencing Design and Construction," A. L. Brake, 6 p.m. ★ MIDLAND COUNTIES GRADUATES' AND STUDENTS' SECTION : Engineering Centre, Stephenson Place, Birmingham, " Report on a Visit to Brazil, Venezuela and Mexico," Denis Matthews, 6.30 p.m.

IRON AND STEEL INSTITUTE

Wed. and Thurs., March 1 *and* 2.—4, Grosvenor Gardens, London, S.W.1, Forty-Second Meeting of the Iron and Steel Engineers Group, Wed., 2.30 p.m., Thurs., 10 a.m. and 2.30 p.m.

JUNIOR INSTITUTION OF ENGINEERS

To-day, Feb. 24.—Pepys House, 14, Rochester Row, Westminster, S.W.1, " Traffic Engineering in Urban Areas," J. T. Duff, 7 p.m.

Wed., March 1.—MIDLAND SECTION : James Watt Memorial Institute, Great Charles Street, Birmingham, Repetition of Presidential Address, " The Development Engineer in the Petroleum Industry," E. S. Sellers, 7 p.m.

Fri., March 3.—Pepys House, 14, Rochester Row, Westminster, S.W.1, Film " The Kariba Hydro-Electric Scheme, Parts 1, 2 and 3," introduced by T. A. L. Paton, 7 p.m.

NEWCOMEN SOCIETY

Wed., March 1.—Science Museum, South Kensington, London, S.W.7, " The Early Development of the Trolley-Bus," A. S. Crosley, 5.30 p.m.

NORTH EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS

To-day, Feb. 24.—Lecture Theatre, Mining Institute, Neville Hall, Newcastle upon Tyne, " Fatigue Strength of Marine Shafting," G. P. Smedley, and B. K. Batten, 6.15 p.m.

REINFORCED CONCRETE ASSOCIATION

Fri., March 3.—SOUTH WALES AND MONMOUTHSHIRE BRANCH : South Wales Institute of Engineers, Park Place, Cardiff, " Lift Slab Design and Construction," F. R. Benson, 6 p.m.

ROYAL AERONAUTICAL SOCIETY

Fri., March 3.—ROTORCRAFT SECTION : Lecture Theatre, 4, Hamilton Place, London, W.1, " Helicopter Approach Aids," H. W. Mitchell and S. G. Lennox, 7 p.m.

ROYAL INSTITUTION OF GREAT BRITAIN

To-day, Feb. 24.—21, Albemarle Street, London, W.1, " Radio Astronomy and Cosmology," Martin Ryle, 9 p.m.

Fri., March 3.—21, Albemarle Street, London, W.1, " The Development of X-Ray Analysis," Sir Lawrence Bragg, 9 p.m.

ROYAL INSTITUTION OF NAVAL ARCHITECTS

Tues., Feb. 28.—Institute of Marine Engineers, 76, Mark Lane, London, E.C.3, " Lloyds Rules for a Nuclear Ship," J. M. Murray, and H. N. Pemberton, 5.30 p.m.

SOCIETY OF CHEMICAL INDUSTRY

Tues., Feb. 28.—CORROSION GROUP : 14, Belgrave Square, London, S.W.1, Cathodic Protection Panel Meeting, " External Protection of Floating Craft," M. G. Duff and P. Clark, 6 p.m.

SOCIETY OF INSTRUMENT TECHNOLOGY

Tues., Feb. 28.—Manson House, 26, Portland Place, London, W.1, " Three Terminal Bridge Measurements and Automation," V. S. Griffiths, 6.30 p.m.

WEST OF SCOTLAND IRON AND STEEL INSTITUTE

To-day, Feb. 24.—39, Elmbank Crescent, Glasgow, Joint meeting with the Engineers' Group, Iron and Steel Institute, " Layout and Design of a Hot Strip Mill," M. F. Dowding, C. Sturdy and A. A. Thomas, 6.45 p.m.

Advanced Engineering Courses

The Fracture of Metals. BATTERSEA COLLEGE OF TECHNOLOGY, Metallurgy Department, London, S.W.11. A three-and-a-half-day course, April 11 to 14, intended to give an overall picture of recent work in this field. The topics to be covered will include : the practical problems of fracture in service ; mechanical testing methods for the assessment of fracture behaviour ; theoretical aspects of fracture ; the ductile to brittle transition in ferrous and non-ferrous metals ; the effect of irradiation on fracture behaviour ; temper brittleness in steels ; hydrogen embrittlement of metals ; fracture under creep conditions ; fracture under fatigue conditions. Fee £10 10s.

The Design of Industrial Experiments. THE UNIVERSITY OF BIRMINGHAM, Institute for Engineering Production, " Southfield," 16, Norfolk Road, Edgbaston, Birmingham, 15. Residential executive course, April 10 to 21. The course covers the theory of experimental design from the basic principles to the analysis and interpretation of the results. It is intended for members involved in quantitative investigational work in any section of industry. The inclusive charge for the normal two-week residential course covering course papers and all residential charges and meals is 60 guineas.